1. Title Page

OLD DOMINION UNIVERSITY

MET 330 CONTINENTAL AG Design Project

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2. Abstract

This project covers the design of a coolant pipeline to satisfy an automated machining line for a new manufacturing facility based in Dayton, Ohio. The client commissioned the line to have five machines, all of which are supplied with coolant from one main reservoir. The system includes three separate holding tanks, one for receiving deliveries of new coolant from railway, one for exchanging with the machining line, and one for takeaway of dirty coolant to trucks. Each tank is connected through a pump and pipeline designed to achieve a target flowrate to accommodate the client's desired capacity.

The fluid to be handled is coolant with corrosive properties similar to water. Grade 304 Stainless Steel was selected as the material of choice for all pipelines and tanks for its strong corrosion resistance and strength compared to PVC. Pipeline analysis has shown the system to be resistant to all common fluid handling concerns, namely pipeline sag, water hammer, and pump cavitation. Furthermore, the pipelines and tanks were located as such to minimize insulation costs to avoid freezing during low ambient temperature conditions.

All reasonable accommodations were made to simplify the pipeline design and provide for ease of maintenance. This includes maintenance valves upstream and downstream of each pump, check valves downstream of each pump, a blind flange for future process connection, and a proposed open channel design should the client need to drain a tank in the future.

3. Table of Contents

4. List of Figures and Tables

5. Report Body

5.a. Job Site Location

The jobsite is located in Dayton, Ohio.

5.b. Specifications and Design Philosophy

For each tank, the time required to fill, and empty was decided by the data provided by the client. The times to fill and empty were fixed as follows:

- Railway to Railway Tank – 4 hours – half a shift
- Railway Tank to Machining Tank – 2 hours – quarter of a shift
- Machining to Truck Tank – 2 hours – quarter of a shift
- Truck Tank to Truck – 4 hours – half a shift.

The railcar and trucks are low priority load points and as such were selected at 4 hours to provide a reasonably fast fill time without excessive cost. The railway tank to machining tank and machining to truck tank fill times were decided based on the client having one 8-hour shift per week in which the tank must be completely emptied and then refilled. A total empty and fill time of 4 hours provides ample time to complete this task without risking delaying the restart of the production line.

5.c. Sources

- Full Pipeline System Design of a Manufacturing Plant for CONTINENTAL AG; Ayala; 2021
- Mott R. and Untener J. Applied Fluid Mechanics. 7th Edition. Pearson. 2014.
- “49 CFR Subpart E - Welding of Steel in Pipelines.” *Legal Information Institute*, Legal Information Institute, https://www.law.cornell.edu/cfr/text/49/part-192/subpart-E.
- Engineering ToolBox, (2001). [online] Available at: https://www.engineeringtoolbox.com [Accessed 10/11/2022]
- R.C. Hibbeler. Mechanics of Materials. 9th edition. Prentice Hall. 2013.
- Sulzer Pump Catalog, Series 2.00 (ISO Units), Type Ohh Horizontal, Single Stage, Radially Split, Centerline Mounted Iso 13709 (Api 610) Type Oh2 Process Pump. Pages 231, 232, 367, 368, 371 & 398.

5.d. Materials and Specifications

5.d.i. Pipe and Tank material

- All tanks in this design are Grade 304 Stainless Steel
- All pipelines in this design are Grade 304 Stainless Steel

5.d.ii. Fluid Characteristics

- Coolant is the pumped fluid and is assumed to have a specific gravity of 0.94, a freezing point of 0^{o}F, corrosiveness similar to water, and viscosity and vapor pressure equal to 1.50 times that of water at any temperature.
- All processes will be isothermal, and the coolant is incompressible.

5.e. Preliminary Drawings and Sketches

5.e.i. Plot Plan

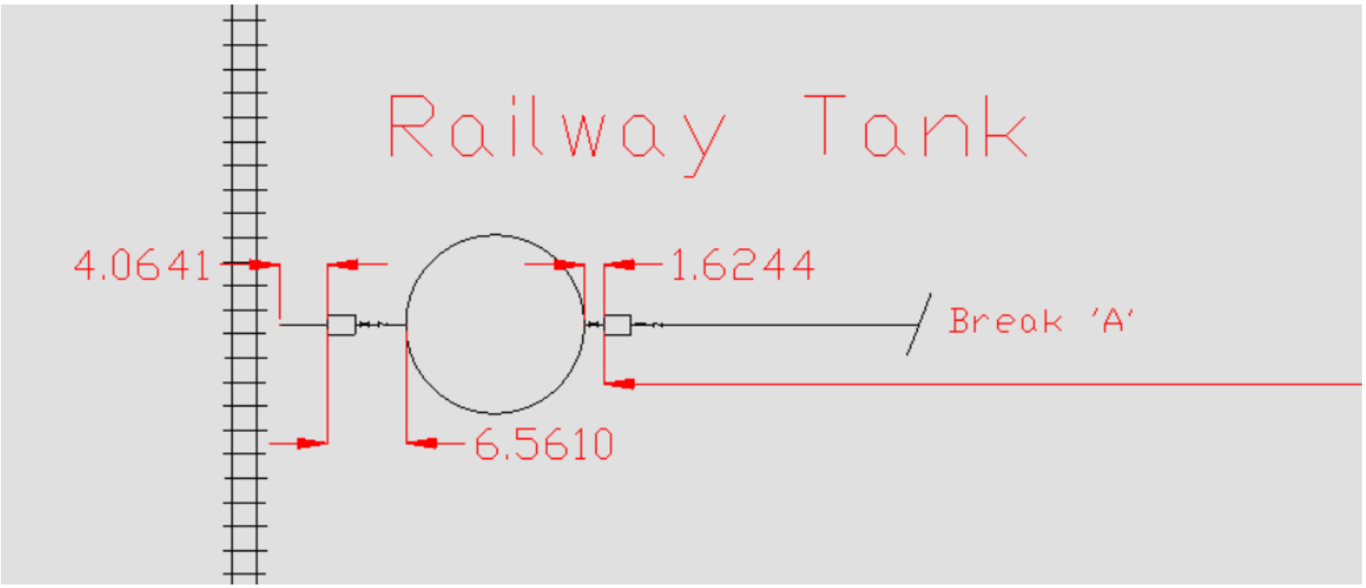


Figure 5-1 Railway Tank Preliminary Plot

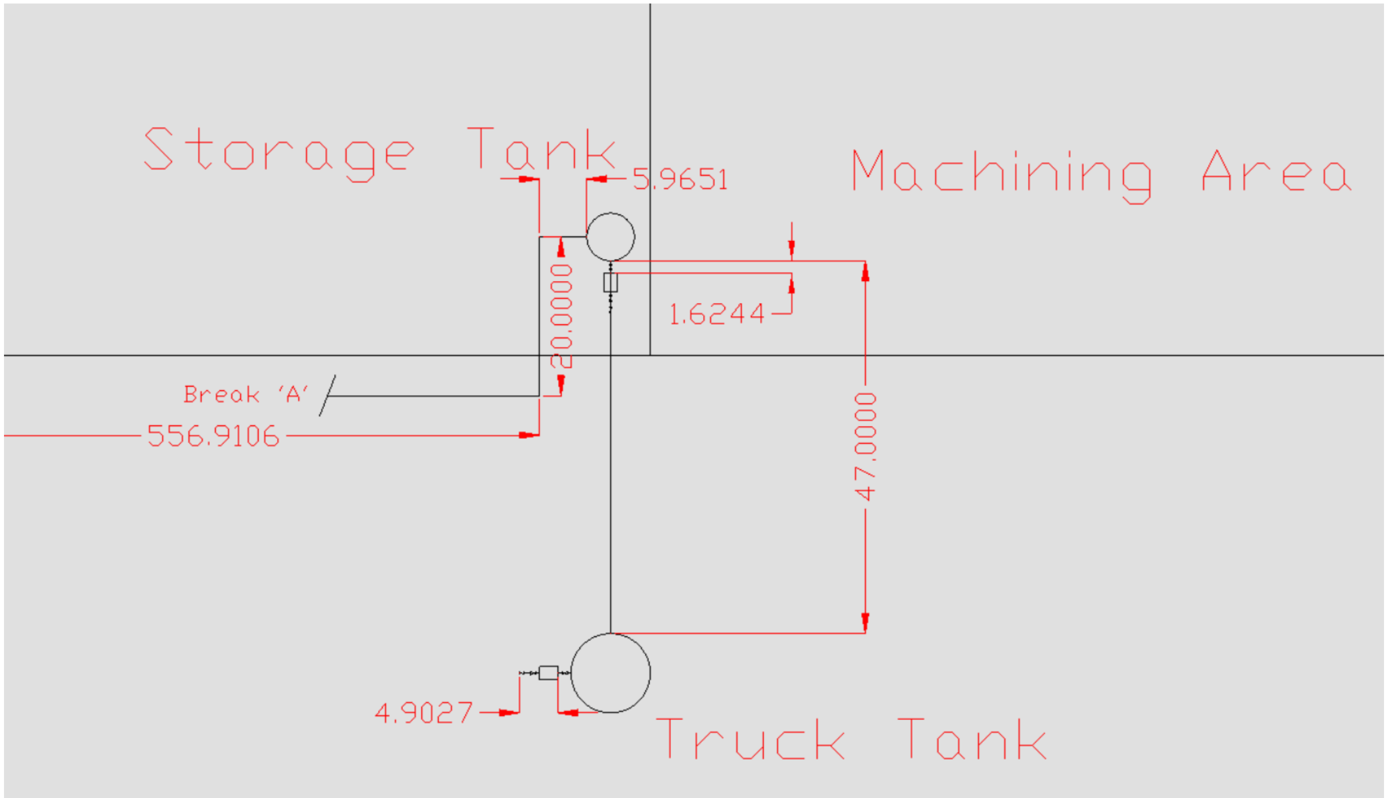


Figure 5-2 Machining Area and Truck Tank Preliminary Plot

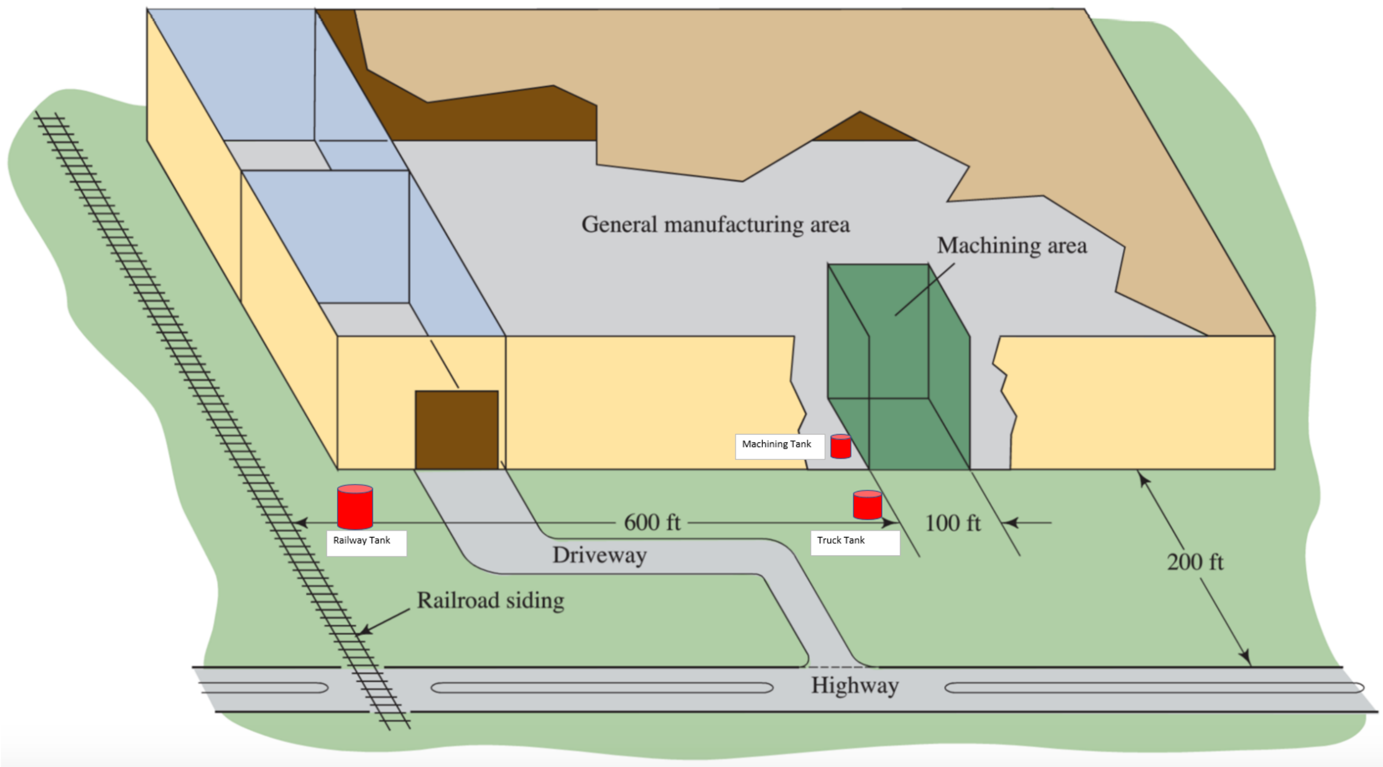


Figure 5-3 Marked Up Preliminary Isometric

5.e.ii. Elevations

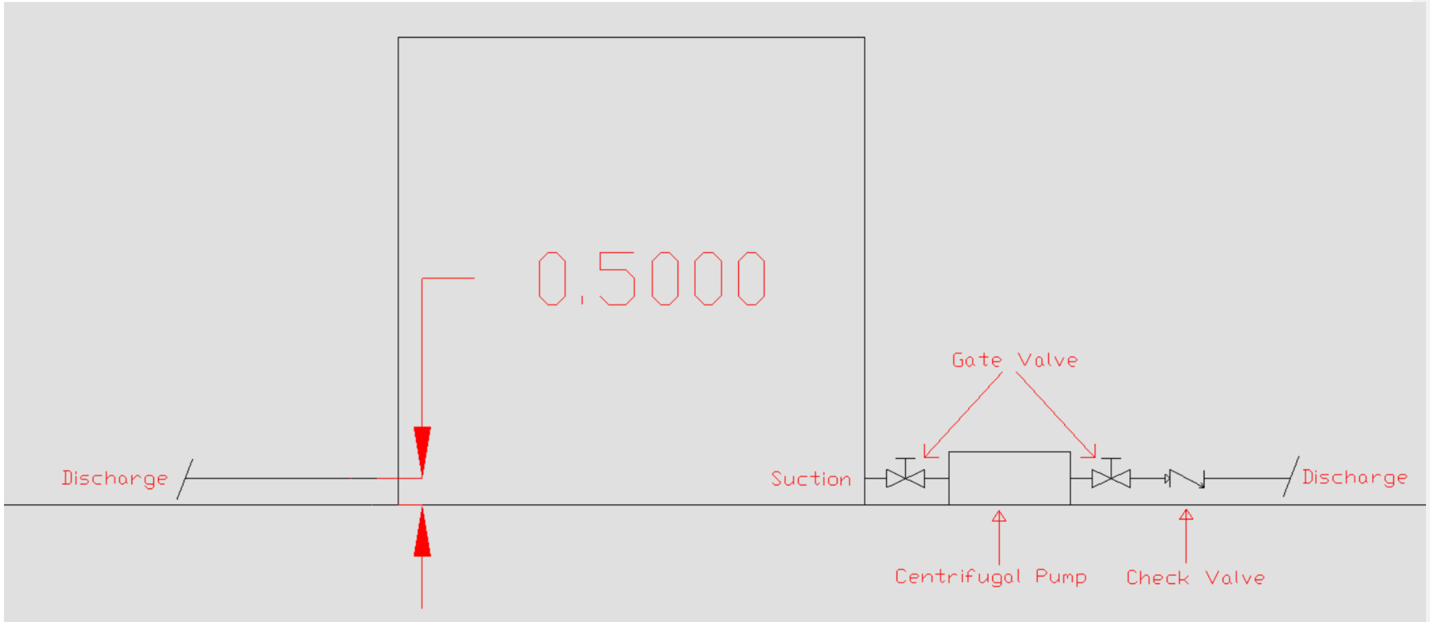


Figure 5-4 Typical Preliminary Elevation for all tanks

5.f. Design Calculations

5.f.i. Tank Specifications

5.f.i.01. Location

Purpose:
Select a location for each tank that will minimize pipeline length and cost while maximizing accessibility.

Data and Variables
Drawing provided of the hypothetical facility is used to select tank locations.
The manufacturing facility is 200ft offset from the highway.
The machining area is 600ft offset from the railroad and is 100ft in length.
The building is in Dayton, Ohio, where the outside temperature may range from -20°F to +105°F.

Procedure
A coordinate system is established with the intersection of the highway and the railroad track being defined as the origin. The manufacturing facility and all components are located some positive 'x' distance and some positive 'y' distance from this origin.

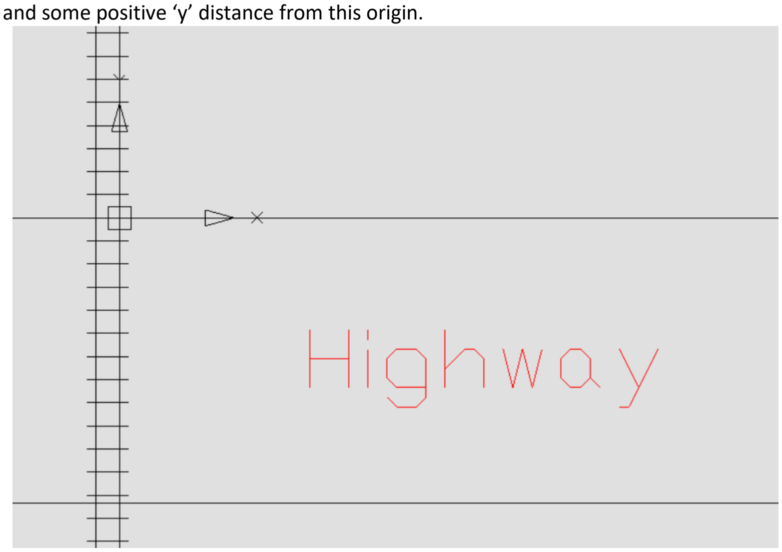


Figure 5-5 Tank Selection Coordinate Origin

Using the data provided by the project block diagram, it is determined that three distinct tanks are required. For each of these tanks we position them as close to the transfer point as possible to minimize pipeline length and friction losses.

Tank #1 is designated as the Railway Tank and is located close to the railway. Using the coordinate system with all dimensions being in feet, the center of tank #1 is located at (20x, 195y).

Tank #2 is designated as the Machining Tank and is located close to the machining area. It is placed inside of the manufacturing facility to reduce insulation and heat tracing requirements. Using the coordinate system with all dimensions being in feet, the center of tank #2 is located at (595x, 215y).

Tank #3 is designated as the Truck Tank and is located close to the highway. Using the coordinate system with all dimensions being in feet, the center of tank #3 is located at (595x, 160y).

Summary

The tanks are located according to the table below:

Table 5-1 Storage Tank Coordinates

Point of interest	XY Coordinates (ft)
Rail/Highway Intersection	(0, 0)
Railway Tank #1	(20, 195)
Storage Tank #2	(595, 215)
Truck Tank #3	(595, 160)
Bottom left corner of machining room	(600, 200)

Analysis

The tanks are placed to minimize distance to the transfer points while still putting one tank inside of the manufacturing facility. These positions will be used to determine the required pipeline layout and dimensions.

5.f.i.02. Size Design

<u>Purpose:</u>
Calculate the required dimensions of each tank to satisfy the coolant storage requirements.

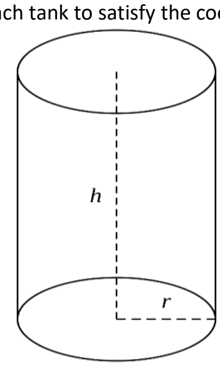


Figure 5-6 Typical Dimensions of a Cylindrical Tank

<u>Data and Variables</u>
Railway Tank #1 must hold at least 15,000 gallons to fully unload a railcar.
Machining Tank #2 must hold at least 1,000 gallons to satisfy the machining system.
Truck Tank #3 must hold at least 4,000 gallons. The truck tank will contain 1,000 gallons per week of dirty coolant and will only be emptied once every four weeks.

<u>Procedure</u>
For each storage tank an upright cylinder is selected as the tank form. The general equation for the volume of a cylinder is used to calculate the storage capacity of multiple tanks. Only cylindrical tanks with height equal to diameter will be considered as this is the most efficient relationship for maximizing the unit volume of a cylinder per unit surface area. Tank dimensions will be up to the nearest 1.0 foot to simplify ease of tank procurement while providing additional safety factor in the tank storage.

After calculating sample tank sizes from 1.0ft to 16.0ft, the volumes are compared to the storage requirements of each tank plus a safety factor of 10%.

<u>Calculations</u>
$h = height\ (ft)$
$A = area\ (ft^2)$
$D = diameter\ (ft)$
$V = Volume\ (ft^3 or\ gal)$
$V_{Railway} = Required\ volume\ of\ railway\ tank = \ 15000\ gal * 1.10 = 16500\ gal$
$V_{Machining} = Required\ volume\ of\ machining\ tank = \ 1000\ gal * 1.10 = 1100\ gal$
$V_{Truck} = Required\ volume\ of\ coolant\ tank = \ 4000\ gal * 1.10 = 4400\ gal$

For a tank diameter of 10.0 ft
$h = D = 10.0ft$
$A = \frac{\pi}{4} * D^2$

$$A = \frac{\pi}{4} * (10ft)^2 = 78.5ft^2$$
$$V = A * h$$
$$V = 78.5ft^2 * 10.0ft * \left(7.48052\frac{gal}{ft^3}\right)$$
$$V = 5875\ gal$$

Using Excel to calculate multiple sizes:

Table 5-2 Available Tank Sizes

	Diameter (ft)	Area (ft^2)	Height (ft)	Volume (ft^3)	Volume (gal)
	1.0	0.8	1.0	1	6
	2.0	3.1	2.0	6	47
	3.0	7.1	3.0	21	159
	4.0	12.6	4.0	50	376
	5.0	19.6	5.0	98	734
Machining	6.0	28.3	6.0	170	1269
	7.0	38.5	7.0	269	2015
	8.0	50.3	8.0	402	3008
	9.0	63.6	9.0	573	4283
Truck	10.0	78.5	10.0	785	5875
	11.0	95.0	11.0	1045	7820
	12.0	113.1	12.0	1357	10152
	13.0	132.7	13.0	1726	12908
	14.0	153.9	14.0	2155	16122
Railcar	15.0	176.7	15.0	2651	19829
	16.0	201.1	16.0	3217	24065

Round the required storage volumes up for each tank to the next table position and select 6.0ft for the machining tank, 10.0ft for the truck tank, and 15.0ft for the railway tank.

Summary

The railway storage tank will be a cylinder of 15.0ft diameter and 15.0ft height. This tank has a max capacity of 19,829 gallons.

The machining storage tank will be a cylinder of 6.0ft diameter and 6.0ft height. This tank has a max capacity of 1,269 gallons.

The truck storage tank will be a cylinder of 10.0ft diameter and 10.0ft height. This tank has a max capacity of 5,875 gallons.

Analysis

Each storage tank is selected as a cylinder where the height is equal to the diameter. This maximizes the relationship between volume and surface area. Each tank is slightly oversized compared to the bare minimum capacities to ensure that buffer space is present to avoid overfilling the tanks.

5.f.i.03. Tank Thickness

<u>Purpose:</u>
Calculate the wall thickness of each storage tank to withstand the internal pressure of the stored coolant.

<u>Data and Variables</u>
From tank sizing section:

Table 5-3 Selected Tank Sizes

Location	Tank Diameter (ft)	Tank Height (ft)
Machining	6.0	6.0
Truck	10.0	10.0
Railcar	15.0	15.0

$\gamma_{coolant} = 58.66 \frac{lb}{ft^3}$

<u>Procedure</u>
304 stainless steel is selected as the material for each tank based on the coolant's corrosiveness being approximately the same as water and no special material properties needing to be considered.

Use the following equation to calculate the required wall thickness of each tank:

$$t = \frac{pD}{2(SE + pY)}$$

t= Basic wall thickness
p= Design Pressure (psig) from $p = \gamma_{coolant} h_{tank}$. Assume maximum 100% fill for each tank.
D= Pipe outside diameter (in) from tank diameter
S= Allowable Stress in tension (psi) from material properties of 304 Stainless Steel from Appendix 9-1
E= Longitudinal Joint Quality Factor from 49 CFR Subpart E Appendix 9-2
Y= Correction factor based on material type and temperature from Appendix 9-3

<u>Calculations</u>
For the Railcar Storage tank:

$$p = \gamma_{coolant} h_{tank} = 58.66 \frac{lb}{ft^3} * 15.0ft * \frac{1ft^2}{144in^2} = 6.11\ psig$$

$D = 15.0\ ft$
$S = 30\ ksi = 30{,}000psi$ from Appendix 9-1
$E = 0.80$ from Appendix 9-2
$Y = 0.4$ from Appendix 9-3

$$t = \frac{pD}{2(SE + pY)}$$

$$t = \frac{6.11psi * 15.0ft * \frac{12in}{ft}}{2(30000psi * 0.80 + 6.11psi * 0.4)}$$

$$t = 0.023in$$

Summary

Duplicating the calculations for each tank results in the following calculated minimum wall thickness.

Table 5-4 Calculated Minimum Wall Thickness for Selected Pipelines

Location	Diameter, D (ft)	Height, h (ft)	Design Pressure, p (psi)	Allowable Tensile Stress, S (psi)	Longitudinal Joint Quality Factor, E	Correction Factor, Y	Calculated Minimum Wall Thickness, t (in)
Machining	6.0	6.0	2.44	30000	0.8	0.4	0.004
Truck	10.0	10.0	4.07	30000	0.8	0.4	0.010
Railcar	15.0	15.0	6.11	30000	0.8	0.4	0.023

Location	Selected Wall Thickness, t (in)
Machining	0.0625
Truck	0.0625
Railcar	0.0625

Analysis

304 stainless steel is selected as the material of choice due to its strong rust and corrosion resistance and proven ability to handle waterlike substances with a long lifetime. Greater strength stainless steel is not required as the pressures used in this pipeline system are well below the strength of 304 stainless steel.

The calculation method for required minimum wall thickness of the tanks is identical to the calculation method later used for required minimum wall thickness of the pipelines. Although the tanks are not expected to be filled to 100% full, all calculations were done assuming the worst-case scenario on pressure to provide safety factor.

5.f.i.04. Future Drain Connection – Blind Flange Design

<u>Purpose</u>

The client has requested an additional drain connection to be added to the main storage tank of the coolant rail car storage tank, for future drain connections. The pressure of the tank has been assessed and using the pressure of the main storage tank a usable Blind flange has been selected.

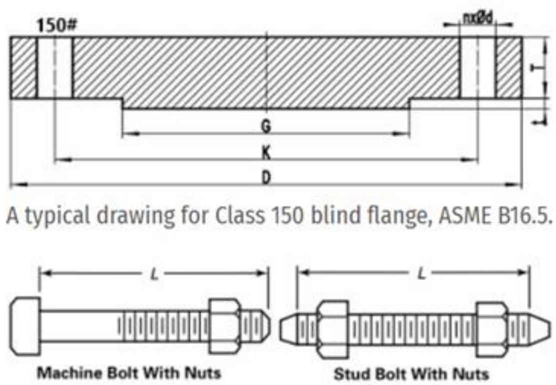


Figure 5-7 Typical Dimensions for a Class 150 Blind Flange, ASME B16.5

<u>Data and Variables</u>

From the basic dimensions of the Coolant railcar storage tank.

Diameter (ft)	Area (ft^2)	Height (ft)	Volume (ft^3)	Volume (gal)	Pressure max (lb/ft^2)	Pressure max (psi)
15	176.71	15	2650.71	19828.75	879.84	6.11

<u>Procedure</u>

Using these proportions for the tank we can determine that the max pressure of the tank is well within the range of the ASME class 150 Stainless Steel Blind Flange, which is rated for ~150 psi.
Selecting a flange size fixes all remaining dimensions of the flange and the bolts.

Summary

Selecting 1-1/4 NPS as the flange size results in the following dimensions.

NPS	D (mm)	K (mm)	G (mm)	T (mm)
1-1/4	115	63.5	88.9	14.3

NPS	N (number of bolts)	d (diameter of bolt holes) (mm)	I (diameter of bolts) (mm)	Length of bolt (mm)
1-1/4	4	5/8	1/2	70

Analysis

All commercially available ASME B16.5 Class 150 Blind Flanges will far exceed the safety factor required for this system design. This is a result of small storage tanks that are open to the atmosphere. Thus, high pressures approaching 150 psi are not capable of occurring in these tanks.

5.f.i.05. Wind Load and Weight

Purpose

Calculate the wind load and external conditions felt by the tanks above ground.

Drawings/Diagrams

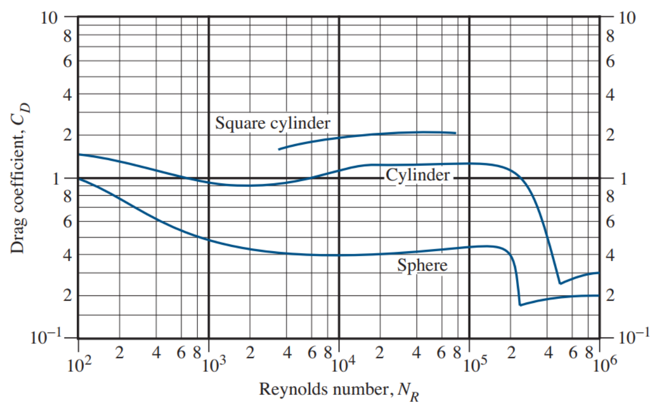


Figure 5-8 Drag Coefficient for Square Cylinder Profiles

Data and Variables

A maximum wind velocity of 40mph (58.66 ft/s) was used to find the maximum wind force.

Coolant Density:
Air Density: 0.062 lb/ft^3
Air Velocity: 14.667 ft/s
Drag Coefficient: 0.300
Weight of Tank: $((Specific\ Weight\ of\ Stainless\ Steel) * (Volume\ of\ Stainless\ Steel)$
Drag Force: $(Drag\ Coefficient)(\frac{pv^2}{2})(A)$
Specific Weight of Stainless Steel: 495.05 lb/ft^3

Location	Diameter (ft)	Area (ft^2)	Height (ft)	Volume (ft^3)	Volume (gal)
Machining	6.0	28.3	6.0	169.6	1269.0
Truck	10.0	78.5	10.0	785.4	5875.2
Railcar	15.0	176.7	15.0	2650.7	19828.8

Procedure

Use equations for Reynold's number as well as drag coefficient to find the wind load conditions. Due to the high Reynold's number, the drag coefficient is assumed to be 0.300 for all tanks. Refer to Figure 5.8.

Calculate the weight of the fluid and the weight of the tank for the total combined weight.

Calculations

Reynold's Number for Machining Tank: $Re = \frac{(14.667)(6)}{(1.37x10^{-4})} = 642350$

Drag Force of Machining Tank: $0.300 * 0.062 \frac{lb}{ft^3}\left(\frac{\left(14.667\frac{ft}{s}\right)^2}{2}\right) * (6ft)^2 = 72.5\ lb$

Weight of fluid in the machining tank:

$$1269\ gallons * \frac{ft^3}{7.48\ gallons} * 58.66 \frac{lb}{ft^3} = 9951\ lb$$

Weight of machining tank:
From Table 5.4: Selected wall thickness is 0.0625in.

$$V_{Tank} = \pi dh + \frac{2\pi}{4} d^2 * t$$

$$V_{Tank} = \pi(15ft)(15ft) + \frac{2\pi}{4}(15ft)^2 * \left(\frac{0.0625in}{\frac{12in}{ft}}\right) = 5.52\ ft^3$$

$$Weight_{Tank} = 5.52ft^3 * 495.05 \frac{lb}{ft^3} = 2736\ lb$$

Summary

The drag forces and weights for the remaining tanks were calculated and displayed below:

Location	Diameter (ft)	Area (ft^2)	Height (ft)	Volume (ft^3)	Volume (gal)
Machining	6.0	28.3	6.0	169.6	1269.0
Truck	10.0	78.5	10.0	785.4	5875.2
Railcar	15.0	176.7	15.0	2650.7	19828.8

Figure 5-9 Drag Force and Weights of Tanks

Location	Fluid Weight (lb)	Tank Weight (lb)	Total Weight (lb)	Drag Force (lb)
Machining	9950.8	437.2	10387.9	72.5
Truck	46068.3	1216.3	47284.6	201.4
Railcar	155480.6	5475.3	160955.8	453.0

Analysis

The provided total weight and drag force will inform the civil structure requirements to support the tanks. As the tank volume increases the total weight increases drastically compared to the drag force as a result of the square-cube law.

5.f.i.06. Open Channel for Drainage

Purpose

Determine the depth of an open channel designed to dump the dirty coolant in the event the 5875-gallon tank fails and needs to be emptied before repairs can be conducted.

Drawings/Diagrams

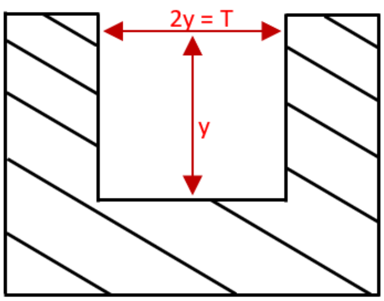


Figure 5-10 Cross Section of most efficient half of a square open channel

Design Considerations

The flow in the open channel will be subcritical turbulent.
The open channel will be designed to handle 15% more than the design flowrate.

Data and Variables

Tank Volume = 4000 gal
Velocity "V" = 10.036 $\frac{ft}{s}$
Volumetric Flowrate "Q" = 0.019 $\frac{ft^3}{s}$
Increasing "Q" by 15% = 0.019 $\frac{ft^3}{s}$ * 1.15 = 0.022 $\frac{ft^3}{s}$
Resistance Factor "Manning's n" for formed concrete = 0.017
Slope "S" = 0.1% = 0.001

Procedure

$$Q = \frac{1.49}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Rearrange to solve for A*R since both are functions of the unknown, y:

$$AR^{\frac{2}{3}} = \frac{nQ}{1.49 S^{\frac{1}{2}}}$$

$$A = 2.0y^2$$

$$R = \frac{y}{2}$$

Solve for y by plugging in knowns and rearranging equations.

Calculations

$$AR^{\frac{2}{3}} = \frac{0.022\frac{ft^3}{s} * 0.017}{1.49 * 0.001^{\frac{1}{2}}}$$

$$AR^{\frac{2}{3}} = 0.00794$$

Remember: $A = 2.0y^2$ & $R = \frac{y}{2}$

$$2.0y^2 * \left(\frac{y}{2}\right)^{\frac{2}{3}} = 0.00794$$

$$\left(\frac{2.0}{2^{\frac{2}{3}}}\right) * y^{\frac{8}{3}} = 0.00794$$

$$y^{\frac{8}{3}} = \frac{0.00794 * 2^{\frac{2}{3}}}{2.0}$$

$$y = \sqrt[8/3]{\frac{0.00794 * 2^{\frac{2}{3}}}{2.0}}$$

$$y = 0.15ft$$

$$y = 1.8\ in$$

Summary

An Open Channel with a height of 1.8 inches and a width of 3.6 inches is required to empty the 5875 gallon tank in approximately 11.5 hours.

Analysis

The open channel is very shallow because of the very low flow rate used to design it.

5.f.ii. Flow Rate

5.f.ii.01. Tank Fill/Empty Times and Desired Flow Rate

Purpose:
Fix the required flow rate for each pipeline according to the tank fill/empty times.

Data and Variables
Times to fill and empty each tank from section 5.b. of this report

- Railway to Railway Tank – 4 hours – half a shift
- Railway Tank to Machining Tank – 2 hours – quarter of a shift
- Machining to Truck Tank – 2 hours – quarter of a shift
- Truck Tank to Truck – 4 hours – half a shift.

Procedure
Use the tank volumes and time to fill to calculate flow rate.

Calculations

$$\left(\frac{15000gal}{4hrs*60min}\right)*0.002228\left(\frac{\frac{ft^3}{s}}{gal}\right)=0.139\frac{ft^3}{s}$$

Summary
Repeating calculations for all tanks results in the following table:

Table 5-5 Calculated Flow Rates for each Pipeline

Volume (gal)	Time to Fill (hrs)	Q (Flow rate) (ft^3/s)
15000	4	0.139
1000	2	0.019
1000	2	0.019
4000	4	0.037

Analysis
The critical flow rate is for filling and emptying the 1000-gallon tank, as this directly drives the capability of the facility to operate. It is critical that for this project the time to fill and empty the 1000-gallon tank be considered a minimum flow rate. The railway tank and truck tank are not critical and can accept changes to flow rate if required by pump selection.

5.f.iii. Pipe Sizing

5.f.iii.01. Piping Layout and Lengths

<u>Purpose</u>
Determine the piping layout to minimize cost and pump head requirements.

<u>Drawings/Diagrams</u>
Reference section 5.e. for all preliminary drawings.

<u>Procedure</u>
Using CAD, pipelines were drawn running from each storage tank. Pipelines are drawn as straight as possible and are all at the same elevation. Each tank is filled and empty from the side at an elevation of 0.5’ above tank bottom. CAD is used to measure the suction and discharge pipe lengths for each pump and tabulate the results.

Special consideration is given to the 600’ long pipe running from the Railway tank to the Machining tank. To reduce insulation and heat tracing costs, this pipe runs 3’ under grade to put it below the frost line. Running the pipe underground only adds two 90^o elbows and 6’ of pipe length.

<u>Summary</u>
From CAD, the following pipe lengths are established to achieve the desired layout between tanks.

Pump Location	Suction Pipe Length (ft)	Discharge Pipe Length (ft)
Pump - Railway to Railway Tank	6.5	6.5
Pump - Railway Tank to Machining	1.6	589
Pump - Machining to Truck Tank	1.6	45.4
Pump - Truck Tank to Truck	1.6	4.9

<u>Analysis</u>
The pipe layout minimizes elbows while still taking advantage of burying pipe under the frost line to simplify pipe supports and reduce insulation requirements. The pipe sizes are selected to achieve a target velocity given the flow rate and are pulled from standard SCH40 NPS tables. The material of all pipes and components are selected as 304 SS to match the tanks.

5.f.iii.02. Pipe Diameters and Velocities

Procedure
Select appropriate pipe sizes to accommodate target flow rate.

Data & Variables
From 5.f.ii.01:

Pump Location	Volume (gal)	Time to Fill (hrs)	Q (Flow rate) (ft^3/s)
Pump - Railway to Railway Tank	15000	4	0.139
Pump - Railway Tank to Machining	1000	2	0.019
Pump - Machining to Truck Tank	1000	2	0.019
Pump - Truck Tank to Truck	4000	4	0.037

Procedure
Flow rate equation:
$Q = vA$, where:
$Q = Volumetric\ flow\ rate$
$v = Flow\ velocity$
$A = Area$

Calculate the pipe flow area to achieve target flow rate and velocity. Use the calculated area to select an appropriate pipe size based on flow rate and hydraulic loss considerations.

Calculations
Calculating nearest pipe diameter

$$A = \frac{Q}{v} = \frac{\left(0.139 \frac{ft^3}{s}\right)}{9.843 \frac{ft}{s}} = 0.0141\ ft^2$$

Comparing the result to the nearest SCH40 NPS flow area selects 1.5” NPS as the pipe size. Repeat for all pipes and recalculate velocity with the new flow rate.

Table 5-6 Selected Pipe Size, Flow Rates, and Fluid Velocities

Pump Location	Volume (gal)	Time to Fill (hrs)	Q (Flow rate) (ft^3/s)	Velocity (ft/s)	Calculated Area (ft^2)	Selected Pipe Size (NPS)	Selected Area (ft^2)	Calculated velocity (ft/s)
Pump - Railway to Railway Tank	15000	4	0.139	9.843	0.0141	**1.50**	0.0141	9.85
Pump - Railway Tank to Machining	1000	2	0.019	9.843	0.0019	**1.00**	0.0060	3.09
Pump - Machining to Truck Tank	1000	2	0.019	9.843	0.0019	**0.50**	0.0021	8.80
Pump - Truck Tank to Truck	4000	4	0.037	9.843	0.0038	**0.75**	0.0037	10.04

In the case of the Railway Tank to Machining pipeline, the originally selected pipe size to achieve critical velocity was 0.5" NPS. Due to the length of the pipeline at 600 ft, this small pipe size resulted in significant friction losses with a calculated total head approaching 500ft. This pipeline was thus upgraded to 1.0" NPS to significantly reduce friction losses and to aid pump selection.

Analysis

Upgrading the long pipeline from the Railway Tank to Machining will increase overall construction costs but will drastically reduce the total cost of ownership of the pipeline due to reduced pump requirements and increased pump efficiency.

5.f.iii.03. Pipe Thickness

Purpose
Determine the minimum thickness of the pipes to satisfy the design pressure.

Drawings/Diagrams

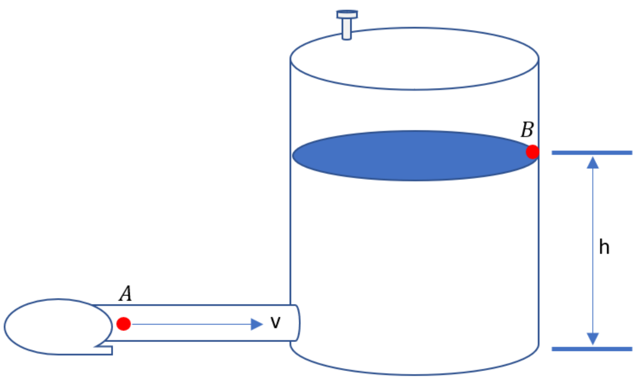


Figure 5-11 Drawing of Bernoulli's Point Selection for Maximum Pipe Pressure

Data & Variables

From tank sizing section:

Location	Tank Diameter (ft)	Tank Height (ft)
Machining	6.0	6.0
Truck	10.0	10.0
Railcar	15.0	15.0

$\gamma_{coolant} = 58.66 \frac{lb}{ft^3}$

$$t = \frac{pD}{2(SE + pY)}$$

t= Basic wall thickness
p= Design Pressure (psig) from $p = \gamma_{coolant} h_{tank}$. Assume maximum 100% fill for each tank.
D= Pipe outside diameter (in) from tank diameter
S= Allowable Stress in tension (psi) from material properties of 304 Stainless Steel from Appendix 9-1
E= Longitudinal Joint Quality Factor from 49 CFR Subpart E Appendix 9-2
Y= Correction factor based on material type and temperature from Appendix 9-3

<u>Procedure</u>

To calculate the pipe wall thickness, the sources found, as well as our section 5.f.v, will be referenced to find each variable in the equation, and then solve for the value t.

For the discharge pressure of the system, select two points where the most information is known. One of those points must be the discharge of the pump to solve for maximum discharge pressure. Cancel terms from the generalized energy equation to solve for the maximum discharge pressure.

$$h_a + \frac{P_a}{\gamma} + \frac{V_a^2}{2g} + z_a = \frac{P_b}{\gamma} + \frac{V_b^2}{2g} + z_b + h_r + h_l$$

$$\cancel{h_a} + \frac{P_a}{\gamma} + \frac{V_a^2}{2g} + \cancel{z_a} = \cancel{\frac{P_b}{\gamma}} + \cancel{\frac{V_b^2}{2g}} + z_b + \cancel{h_r} + h_l$$

$$\frac{P_a}{\gamma} + \frac{V_a^2}{2g} = z_b + h_l$$

$$P_a = \left(z_b + h_l - \frac{V_a^2}{2g}\right) * \gamma$$

The maximum discharge pressure for each case will be realized when $z_b = max$.

<u>Calculations</u>

For Pump – Railway tank to Machining:

$$P_a = \left(z_b + h_l - \frac{V_a^2}{2g}\right) * \gamma$$

$$P_a = (6ft + 39.2ft - 0.149ft) * 58.7\frac{lb}{ft^3}$$

$$P_a = 2639\frac{lb}{ft^2} = 18.3\ psi$$

Calculating minimum pipe wall thickness for 1.0” pipe from railway tank to machining:

$$t = \frac{pD}{2(SE + pY)}$$

$$t = \frac{18.3\ psi * 1.315\ in}{2(1.0 * 30000\ psi + 18.3\ psi * 0.4)}$$

$$\mathrm{t = 0.00040\ in}$$

<u>Summary</u>

Selected pipe thickness is 0.133” for 1.0” NPS SCH40.

0.00040 < 0.133 thus the design is acceptable for 1.0” pipe.

Table 5-7 Pipe Thickness Calculations for each Pipeline

Location	NPS	Design Pressure (*p*) (*psig*)	Pipe outside diameter (D) (in)	Allowable stress in tension (S) (psi)	Longitudinal joint quality factor (E)	Correction factor (Y)	Minimum Thickness (in)	Selected thickness (in)
Pump - Railway to Railway Tank	1.50	9.9	1.900	30000	1	0.4	0.00031	0.145
Pump - Railway Tank to Machining	1.00	18.3	1.315	30000	1	0.4	0.00040	0.133
Pump - Machining to Truck Tank	0.50	5.9	0.840	30000	1	0.4	0.00008	0.109
Pump - Truck Tank to Truck	0.75	10.4	1.050	30000	1	0.4	0.00018	0.113

<u>Analysis</u>

There is no risk of pipe rupture in any of the selected pipelines.

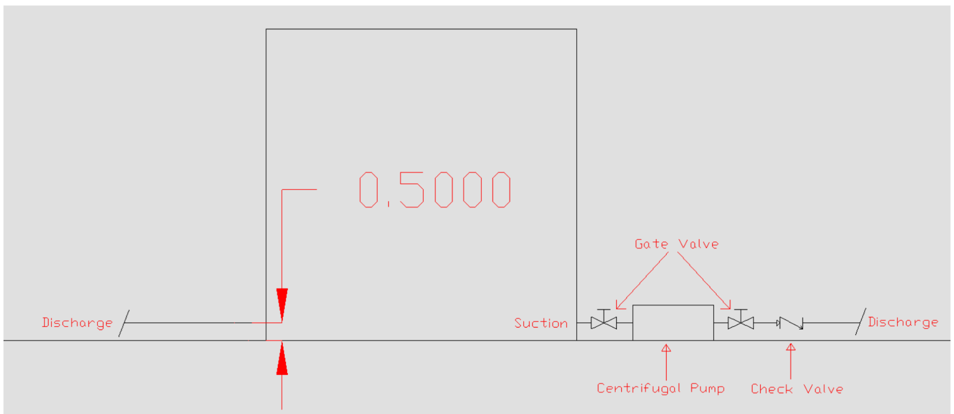
5.f.iii.04. Fittings

Purpose

Determine the fittings used in each pipeline to calculate hydraulic losses.

Drawings/Diagrams

Reference section 5.e. for all preliminary drawings. A typical elevation drawing of a tank shown below is used to tabulate the fittings.



Procedure

From section 5.f.iii.01: Each pump uses the same general form, consisting of a short suction line with a gate valve and a long discharge line with a gate and a check valve. Only the long pipeline from the Railway Tank to the Machining tank uses any elbows, thus minimizing friction losses. The suction side of the Railway to Railway Tank does not include a gate valve because the valve will instead be present on the railway car.

All fittings are counted from the plot plans and elevations and summed into a table.

Summary

Adding to the pipe lengths previously calculated results in the following fitting table.

Table 5-8 Pipeline Lengths and Fittings

Pump Location	Suction Pipe Length (ft)	Suction Pipe Gate Valves	Discharge Pipe Length (ft)	Discharge Pipe Gate Valves	Discharge Pipe Check Valves	Discharge Pipe Elbows
Pump - Railway to Railway Tank	6.5	0	6.5	1	1	0
Pump - Railway Tank to Machining	1.6	1	589	1	1	5
Pump - Machining to Truck Tank	1.6	1	45.4	1	1	0
Pump - Truck Tank to Truck	1.6	1	4.9	1	1	0

Analysis

Each pump uses the same general form, consisting of a short suction line with a gate valve and a long discharge line with a gate and a check valve. Only the long pipeline from the Railway Tank to the Machining tank uses any elbows, thus minimizing friction losses.

5.f.iii.05. Water Hammer

Purpose:

Analyze the pipeline design for water hammer concerns.

Data and Variables

For 1.0” NPS pipeline:

v	= 3.09 ft/s	; From section 5.f.ii
D	= 0.0874 ft	; From section 5.f.ii
δ	= 0.0111 ft	; From section 5.f.ii
$\rho_{coolant}$	= 58.66 lb/ft^3	; From coolant specific gravity
E	= 2.9 * 10^7 psi	; Elastic modulus of steel from section 5.f.iii
E_o	= 3.16 * 10^5 psi	; Bulk modulus of coolant assumed to be same as water

Procedure

Use the water hammer equations to solve for the speed of the pressure wave in the coolant followed by the change in pressure from water hammer. Add the water hammer pressure to the pipeline thickness calculations completed in section 5.f.iii to determine new minimum pipe thickness.

$$C = \frac{\sqrt{\frac{E_o}{\rho}}}{\sqrt{1 + \frac{E_o D}{E\delta}}}$$

$$\Delta P = \rho V C$$

Calculations

For the 1.0” NPS pipeline:

$$C = \frac{\sqrt{\frac{E_o}{\rho}}}{\sqrt{1 + \frac{E_o D}{E\delta}}} = \frac{\sqrt{\frac{3.16 * 10^5\, psi}{58.66\,\frac{lb}{ft^3}}}}{\sqrt{1 + \frac{(3.16 * 10^5\, psi) * 0.0874\, ft}{(2.9 * 10^7\, psi) * 0.0111\, ft}}} = 71.217\frac{ft}{s}$$

$$C = 70.4\frac{ft}{s}$$

$$\Delta P = \rho V C = 58.66\frac{lb}{ft^3} * 3.09\frac{ft}{s} * 70.4\frac{ft}{s} = 12784\frac{lb}{ft^2}$$

$$\Delta P = 88.8\frac{lb}{in^2} = 88.8\, psi$$

From section 5.f.iii:
Design pressure of 18.3 psi on the 1.0” pipeline results in a required pipe thickness of 0.00040 in.
Adding 88.8 psi to the design pressure results in a new required pipe thickness of 0.00150 in.

<u>Summary</u>
Updating table 5-7 to include water hammer pressure:

Location	NPS	Design Pressure (*p*) *(psig)*	Pipe outside diameter (D) (in)	Allowable stress in tension (S) (psi)	Longitudinal joint quality factor (E)	Correction factor (Y)	Minimum Thickness (in)	Selected thickness (in)
Pump - Railway Tank to Machining	1.00	18.3	1.315	30000	1	0.4	0.00040	0.133
Water Hammer	1.00	107.1	0.840	30000	1	0.4	0.00150	0.109

Adding this pressure to the design pressures used previously in calculating minimum pipe thickness results in a new pipeline thickness of 0.0150 in which is far below the selected thickness.

<u>Analysis</u>
The selected thickness of the pipeline is ~70 times the required minimum thickness calculated above. Water hammer is not a concern for any of the selected pipelines and materials.

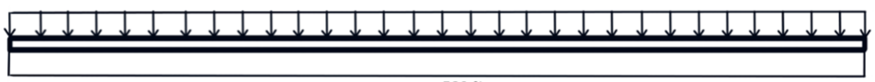
5.f.iv. Pipeline Support Info

5.f.iv.01. Forces on Supports

Purpose

Calculate for each piping system the supports needed to support the weight and forces on the pipe. Pipe deflection shall not exceed 1%.

Drawings/Diagrams



Design Considerations

The process outlined can be repeated for each pipe size as weight, volume, and inertia changes with the pipe sizes. The weight of the fluid and pipe can be modeled as a single point force or a load. In the process used for calculations it is modeled as a load so distance between supports can be calculated. The consideration for the structure length is so that the deflection of the pipe does not exceed 1% of the diameter of the pipe.

Data and Variables

Pipe: Schedule 40 ½ inch pipe	
Outside Diameter	0.840 inch
Pipe Length	589 ft
Pipe Weight	0.85 lb/ft
Specific weight of Coolant	58.656 lb/ft^3
Vmax- 1% of Diameter, Deflection max	7.0e-4 ft
W-Unit weight of pipe + fluid	0.9738 lb/ft
E-Elastic Modulus	2.669e7
I-inertia	1.3434e^{-6} ft^4

Procedures

In order to calculate the load of the pipeline we need the unit weight of a foot segment of the pipe. This can be found by finding the total weight of the pipeline- using volume of the pipe, specific weight of the coolant, pipe length and unit weight of the pipe, which is pulled from the manufacturer- and dividing it by the total pipe length. By using the equation for deflection, pulled from the mechanisms of materials 10th edition, for a load we can rearrange the equation to isolate the variable L for length max between supports. The other variables E can be found for stainless steel at the back of the book. I-inertia of the pipe can be found using the equation for a hollow cylinder and the variable Vmax is the max deflection for the beam or pipe in this case. From there L can be solved for.

Calculations

Pipe Inertia:

$$I = \frac{\pi(D^4 - d^4)}{64}$$

Total Weight of pipe:

$$Total\,Weight = (Pipe\,Volume\,total \cdot Specific\,weight\,of\,coolant) + (Pipe\,Length \cdot Unit\,weight\,of\,pipe)$$

Unit Weight of Pipe (Load-W):

$$W = \frac{Total\,Weight}{Length\,of\,Pipe}$$

Deflection of load:

$$V_{max} = \frac{-5WL^4}{384EI}$$

Isolate Variable L-Length for distance between supports

$$L = \sqrt[4]{\frac{V_{max} \cdot (384EI)}{-5W}}$$

Support Strength

$$Support\,Strength = Unit\,Weight\,of\,Pipe * Distance\,Between\,Supports$$

Summary

The final length between supports is 23.4 ft. This can be applied to all systems with ½ inch schedule 40 steel pipes. The supports need to be able to support a weight of 22.8 lb. In addition, supports need to be added beneath each of the pumps.

Pump Support	Support Weight (lb)
Pump 1	352
Pump 2	514
Pump 3	514
Pump 4	311

Analysis

The support system should withstand the weight of the pipes in the y direction; some alterations in the construction of the supports should be taken into account for the x direction forces of the fluids. As such it is recommended that supports of equal strength are used around pipe joints that alter the direction of the fluid.

5.f.v. Energy Losses

Purpose:
Determine the energy losses throughout the system

Procedure:
To begin, finding the size and strength of the pumps we need for each section, it is important that we find the energy losses. Because the client has requested an average velocity of 3 m/s^2 or 9.84 ft/s^2 for the coolant, this means that our pipe sizes vary between systems to achieve the best results for the clients' requests. This also means the pipe energy losses need to -----be sectioned to account for the change in pipe size. The important values going into the calculation of the energy losses were the fluid specifics. The fluid used is a coolant, assuming constant temperature for now, with a specific gravity of 0.94 and a dynamic viscosity 1.50 times higher than water. The table below shows the found fluid specifics.

Fluid Specifics

Sg	0.94
Specific Weight (lb/ft^3)	58.66
Viscosity (n) ($lb\text{-}s/ft^2$)	0.0000485
Viscosity (v) (ft^2/s)	2.66E-05
Density ($Slugs/ft^2$)	1.82

Once found we can start solving the energy losses. First the pipe loss, therefore it is important to find the fluid specifics because you need to determine laminar or turbulent flow using the Reynolds number. This tells you how to find the friction factor for the pipes. This friction factor can then be plugged into your pipe energy losses equation and the total energy losses through them can be solved. Then the fixtures are to be considered. The energy losses through them are determined by a variable K which can be solved by using the equation specific to the fixture and a friction factor depending on the pipe size. The data can then be used to find your final energy losses.

Calculations:
Finding pipe friction and pipe losses
As stated, these values are very important going forward. For this section they play into the Reynolds number which allows us to know whether the flow through the pipes in laminar flow or turbulent flow. Reynolds number can be found using either the dynamic or kinematic viscosity, the following equation uses the kinematic viscosity.

$$Nr = \frac{VD}{\upsilon}$$

In this case Nr, is our Reynolds number, determining flow, V is the velocity through the pipe, D is diameter of the pipe, and v, is the kinematic viscosity which can be found using the dynamic viscosity and density. This equation needs to be repeated with each of the pipe sizes used in the system. The following table tells us these values.

NPS of pipe (in)	Diameter (ft)	Reynolds number (Nr)
1.5	0.1342	49689
1.0	0.0874	10169
0.5	0.0518	17137
0.75	0.0687	25923

As mentioned before the Reynolds number is important to finding whether your flow is turbulent or laminar, which will affect your pipe friction. The rule for laminar flow vs turbulent flow is the at if the Reynolds number Nr is greater than 4000 the flow will be turbulent. In the case of our system the flow is turbulent through all pipes.

The next step in pipe energy losses is the moody diagram, this tells us the friction factor of our pipes. The axis of the moody diagram are Reynold's number and a variable

$$Relative\ Roughness\ = \frac{D}{\varepsilon}$$

, D references the diameter of our pipes and ε references the pipe roughness with can be found in table 8.2 of the *Applied Fluid Mechanics seventh edition.* Using these values, we can find the friction faction on the Moody diagram shown below.

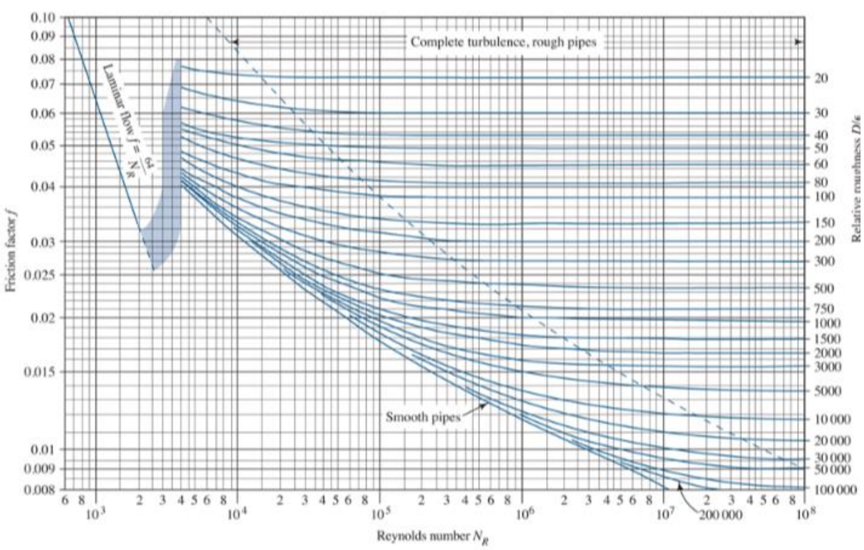


Figure 5-12 Moody Diagram for Friction Factor

Using the above diagram, the friction factor can be found for each of the sized pipes. This brings us to the final step for finding the energy losses through the pipe sections. The final equations for the energy losses through the pipes are calculated by the following equation

$$hL = f * \frac{L}{D} * \frac{V^2}{2g}$$

in this case f is the number we pulled from the moody diagram, and h_L are our energy losses through that section of pipe in lb/ft^2. The table below lays out the energy losses over each section.

This completes the energy losses for the pipes between the railcar to the truck, minus the 4' ft flex hose which will be assumed.

Energy losses for pipe fixtures

To find the energy losses for the pipe fixtures we need to determine the K, resistance for each of the pipe fixtures throughout the system. These can be found in table 10.4 of the *Applied Fluid Mechanics seventh edition.* The energy losses through the entry and exit of each of the tanks also need to be considered. Below is the table for the K coefficient and the formula for the entry and exit values.

The equation below is for gate valves, through the system there are 7 gate valves.

$$K = 8 * Ft$$

The equation below is for check valves, through the system there are 4 check valves.

$$K = 150 * Ft$$

The equation below is for 90-degree elbows, through the system there are 5 elbows.

$$K = 20 * Ft$$

The following equations are for entry and exit valves respectively. These need to be factored in for each tank and the values for each are used assuming that the entry and exit of each tank is a 90-degree corner.

K=1.0

K=0.5

Each of the equations contains a variable f_T which is friction factor in the zone of complete turbulence. It is dependent on the dimensions of the pipes; a table for these variables can be found in the *Applied Fluid Mechanics seventh edition* book under table 10.5. The table can be seen below.

Nominal Pipe Size		Friction
U.S. (in)	Metric (mm)	factor, f_T
½	DN 15	0.026
¾	DN 20	0.024
1	DN 25	0.022
1¼	DN 32	0.021
1½	DN 40	0.020
2	DN 50	0.019
2½	DN 65	0.018

Figure 5-13 F_T for nominal pipe sizes

Commented [NA1]: Need to use superscripts and subscripts instead of ^. This can be done easily with keyboard shortcuts. Ctrl+shift+'=' will go into superscript mode. Ctrl+'=' will go into subscript mode.

Commented [NA2]: Remove for tone. Report should avoid informal language like this.

The K-factor for each gate valve and check valve depend on the pipe size due to f_T. Once the K is found for each fixture the energy losses are calculated. We use the equation

$$hL = K * \left(\frac{V^2}{2g}\right)$$

Below are the minor losses for each of the fixtures.

Calculations

Velocity head per pipeline

Pump Location	SCH 40 NPS	$v^2/2g$ (ft)
Pump - Railway to Railway Tank	1.5	1.506
Pump - Railway Tank to Machining	1.0	0.149
Pump - Machining to Truck Tank	0.5	1.202
Pump - Truck Tank to Truck	0.75	1.564

Table 5-9 Minor Losses for Each Pipeline

Pump 1 -Railcar to Railcar Tank	Resistance factors	Minor Loss h_L (ft)
4' Flex Hose (Assumed)	Unknown	2.00
Gate Valve	$K=8f_T$	0.24
Check Valve	$K=150f_T$	4.52
Rail Tank Square Entrance Loss	K=0.5	0.75
Pump 2 – Railcar Tank to Machine Reservoir		
Rail Tank Square Exit Loss	K=1.0	1.51
Gate Valve X2	K=8Ft	0.05
Check Valve	$K=150f_T$	0.16
90 Degree Elbows X5	$K=20f_T$	0.33
Machine Reservoir Square Entrance Loss	K=0.5	0.07
Pump 3- Machine Reservoir to Dirty Coolant		
Machine Reservoir Square Exit Loss	K=1.0	0.14
Gate Valve X2	$K=8f_T$	0.42
Check Valve	$K=150f_T$	3.97
Dirty Coolant Tank Square Entrance Loss	K=0.5	0.15
Pump 4 - Dirty Coolant to Truck		
Dirty Coolant Tank Square Exit Loss	K=1.0	0.15
Gate Valve X2	$K=8f_T$	0.49
Check Valve	$K=150f_T$	4.57

Table 5-10 Friction Losses for Each Pipeline

Pipe NPS	NPS of pipe	Length (ft)	Energy loss (ft)
1.50	Suction	4' pipe	1.21
1.50	Discharge	6.5' pipe	1.97
1.0	Suction	1.6' pipe	0.09
1.0	Discharge	589' pipe	33.74
0.5	Suction	1.6’ pipe	0.15
0.5	Discharge	45.4’ pipe	34.77
0.75	Suction	1.6' pipe	1.13
0.75	Discharge	4.9' pipe	3.46

Analysis

Table 5-11 Pipeline Total Energy Losses

Pump Location	Total energy losses (ft)
Pump - Railway to Railway Tank	10.69
Pump - Railway Tank to Machining	35.95
Pump - Machining to Truck Tank	40.07
Pump - Truck Tank to Truck	9.80

Above are the total energy losses needed to be compensated by the pumps. The largest energy loss is the machining to truck tank pipeline. Although this pipeline is significantly shorter than the railway tank to machining, the pipe is also smaller resulting in higher friction losses.

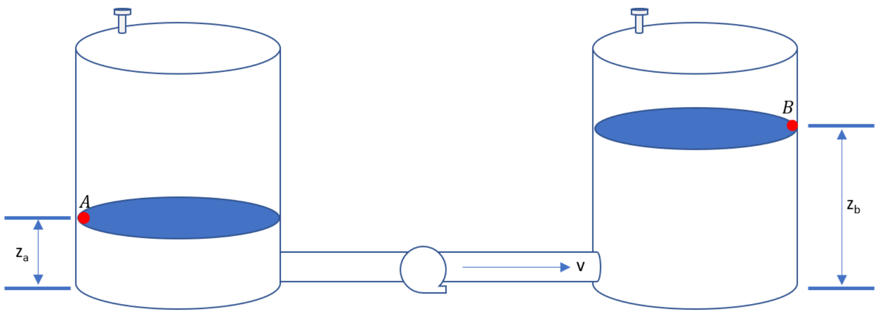
5.f.vi. Pump Selection

5.f.vi.01. Pump Requirements

Purpose:

Determine the pump requirements (head and flow rate) of each pump in the system.

Drawings/Diagrams



Design Considerations:

1) All fluids in the problem are incompressible
2) The process is isothermal

Data and Variables

From hydraulic loss calculations:

Pump Location	SCH 40 NPS	Hydraulic Losses (ft)	Discharge Tank Height (ft)	Flow Rate Q (ft^3/s)
Pump - Railway to Railway Tank	1.5	10.7	15	0.139
Pump - Railway Tank to Machining	1.0	36.0	6	0.019
Pump - Machining to Truck Tank	0.5	40.1	10	0.019
Pump - Truck Tank to Truck	0.75	9.8	13	0.037

Discharge tank size for Truck tank to Truck assumes the height of the pump truck tank to be 13ft.

Procedure

For the system select two points where the most information is known that crosses the pump. These are points A and B where the surface of the tank level has a known pressure and velocity. Cancel terms from the generalized energy equation to solve for the pump head.

$$h_a + \frac{P_a}{\gamma} + \frac{V_a^2}{2g} + z_a = \frac{P_b}{\gamma} + \frac{V_b^2}{2g} + z_b + h_r + h_l$$

The maximum pump head for each case will be realized when $z_a = 0$ and $z_b = max$.

Simplifying the equation leads to the following:

Calculations

For Pump – Railway tank to Machining:

$$h_a + \cancel{\frac{P_a}{\gamma}} + \cancel{\frac{V_a^2}{2g}} + \cancel{z_a} = \cancel{\frac{P_b}{\gamma}} + \cancel{\frac{V_b^2}{2g}} + z_b + \cancel{h_r} + h_l$$

$$h_a = z_b + h_l$$

$$h_a = 6ft + 36.0ft = 42.0ft$$

Summary

Use Excel to tabulate the other pump heads.

Table 5-12 Pump Requirements

Pump Location	SCH 40 NPS	Hydraulic Losses (ft)	Discharge Tank Height (ft)	Flow Rate Q (ft^3/s)	Pump Head (ft)	Pump Flow (gpm)
Pump - Railway to Railway Tank	1.5	10.7	15	0.139	25.7	62.5
Pump - Railway Tank to Machining	1.0	36.0	6	0.019	42.0	8.33
Pump - Machining to Truck Tank	0.5	40.1	10	0.019	50.1	8.33
Pump - Truck Tank to Truck	0.75	9.8	13	0.037	22.8	16.66

Analysis

The worst-case scenario requiring the highest pump head is the scenario where the suction tank is nearly empty, and the discharge tank is nearly full. In this case the pump must overcome the maximum elevation difference between the two tanks as well as the hydraulic losses. The largest pump head is required at the Machining to Truck Tank pipeline primarily driven by friction losses. Our initial selection of 0.5” pipe for the Railway Tank to Machining produced a pump head so high that it necessitated upsizing the pipe to 1.0”.

5.f.vi.02. Selection of pump type

Purpose
Select pump type based on specific speed.

Drawings & Diagrams

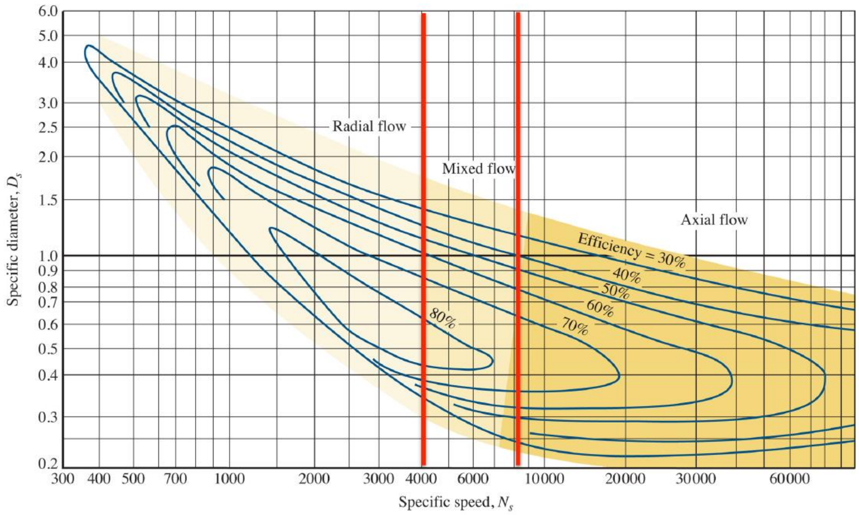


Figure 5-14 Pump Selection by Specific Speed

Data & Variables
From section 5.f.v.01

Pump Location	Pump Head (ft)	Pump Flow (gpm)
Pump - Railway to Railway Tank	25.7	62.5
Pump - Railway Tank to Machining	42.0	8.33
Pump - Machining to Truck Tank	50.1	8.33
Pump - Truck Tank to Truck	22.8	16.66

Procedure

Use the equation for specific speed to select the appropriate pump type.

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$$

where;
N = Rotational speed of the impeller (rpm)
Q = Flow rate through the pump (gal/min)
H = Total head on the pump (ft)

Assume 3600 as the speed for calculating specific speed.

Calculations

- Pump #1
  $N_s = \frac{3600\sqrt{62.383}}{25.7^{\frac{3}{4}}} = 2491.1$ <4000=Radial Flow
- Pump #2
  $N_s = \frac{3600\sqrt{8.527}}{466.5^{\frac{3}{4}}} = 104.7$ <4000=Radial Flow
- Pump #3
  $N_s = \frac{3600\sqrt{8.527}}{53.1^{\frac{3}{4}}} = 534.4$ <4000=Radial Flow
- Pump #4
  $N_s = \frac{3600\sqrt{16.606}}{28.2^{\frac{3}{4}}} = 1198.8$ <4000=Radial Flow

Summary

The total values for pumps one through four are shown in the following table.

Table 5-13 Pump Specific Speeds

Pump Location	Pump Head (ft)	Pump Flow (gpm)	Specific Speed (rpm)
Pump - Railway to Railway Tank	25.7	62.5	2491.1
Pump - Railway Tank to Machining	42.0	8.33	104.7
Pump - Machining to Truck Tank	50.1	8.33	534.4
Pump - Truck Tank to Truck	22.8	16.66	1198.8

Analysis

For all pipelines the specific speed is far below the threshold of radial flow pumps. All pumps can be safely selected as radial pumps with no risk of deviating should the client modify the pipelines. A major change in flow rate or pump head would be required to breach the 4000 rpm threshold.

5.f.vi.03. Pump Curves and System Curves

Purpose:

After having selected a radial pump type, refer to the Sulzer catalog to select a specific pump to satisfy pump requirements.

Drawings/Diagrams:

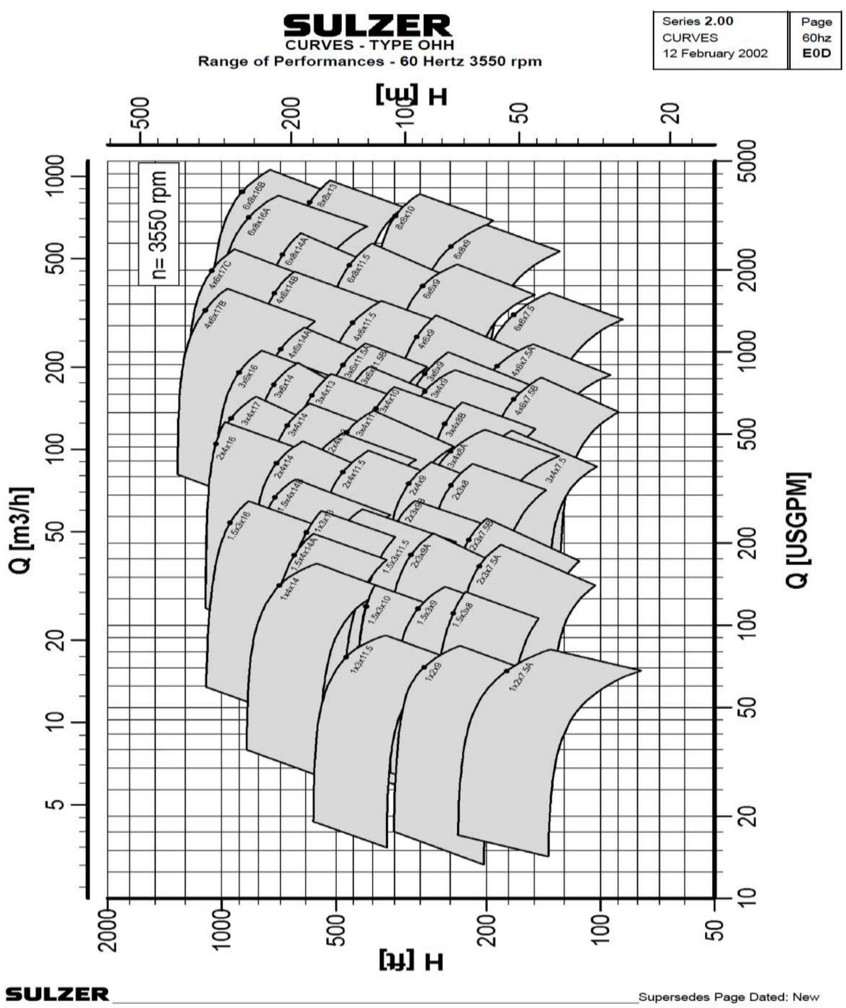


Figure 5-15 Sulzer Pump Performance Given Flow and Head

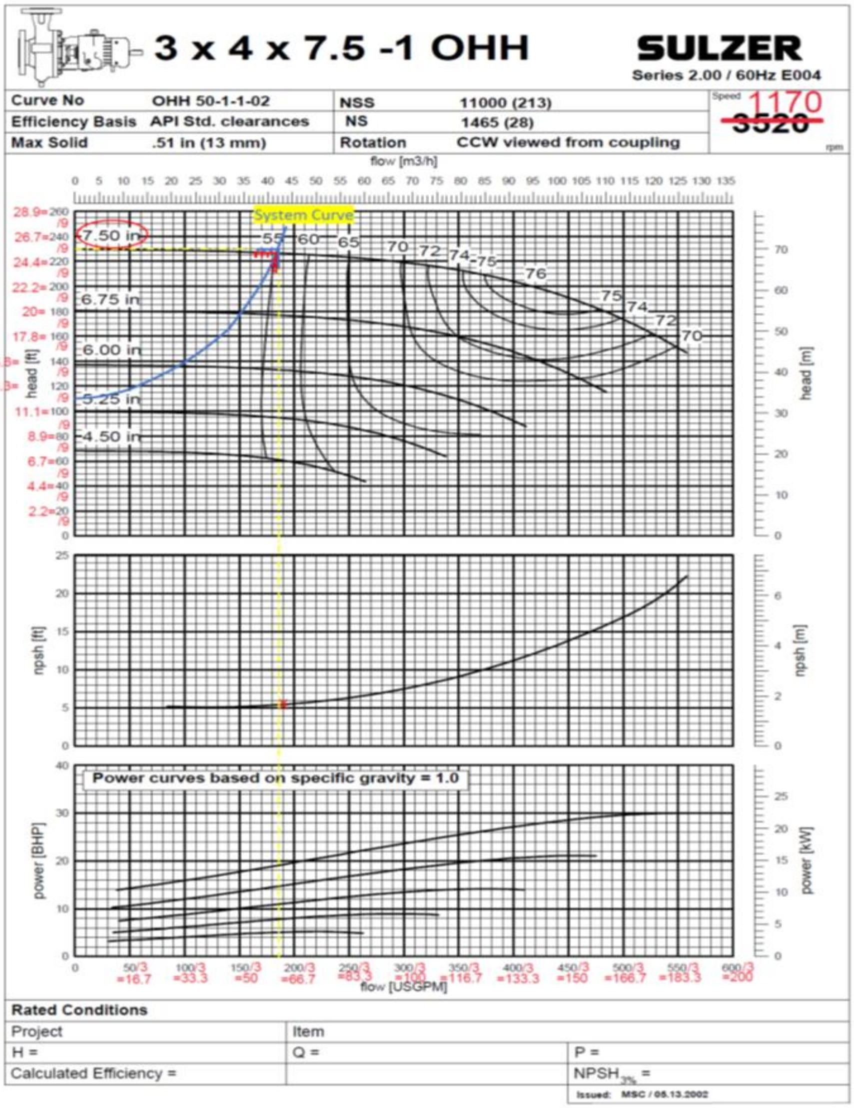


Figure 5-16 Pump #1 Curve

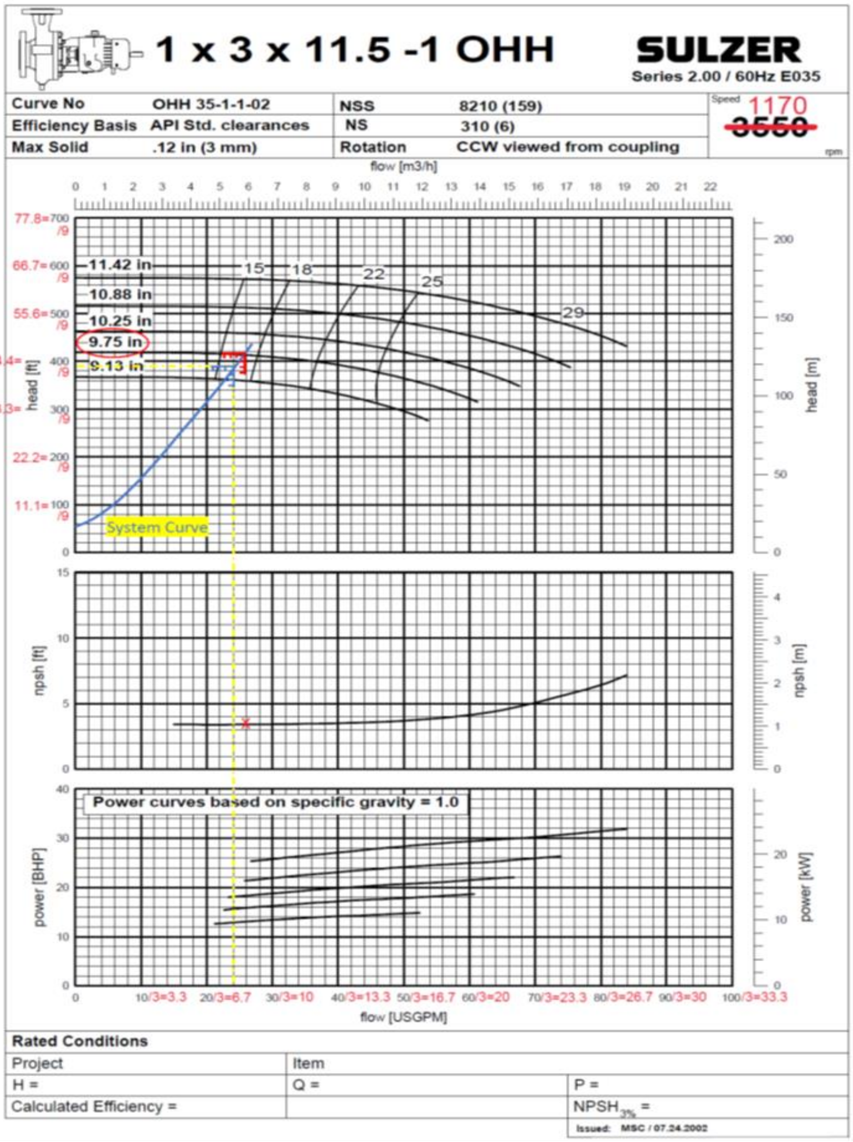


Figure 5-17 Pump #2 Curve

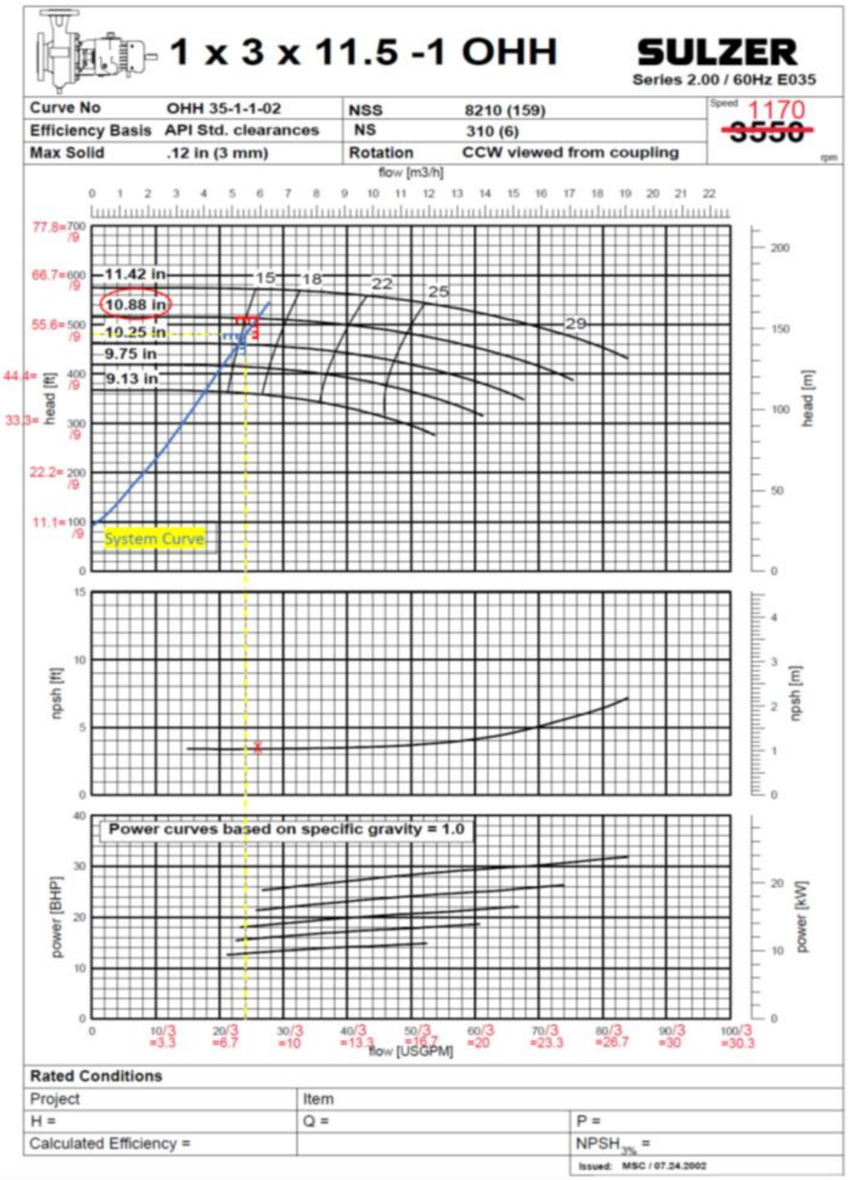


Figure 5-18 Pump #3 Curve

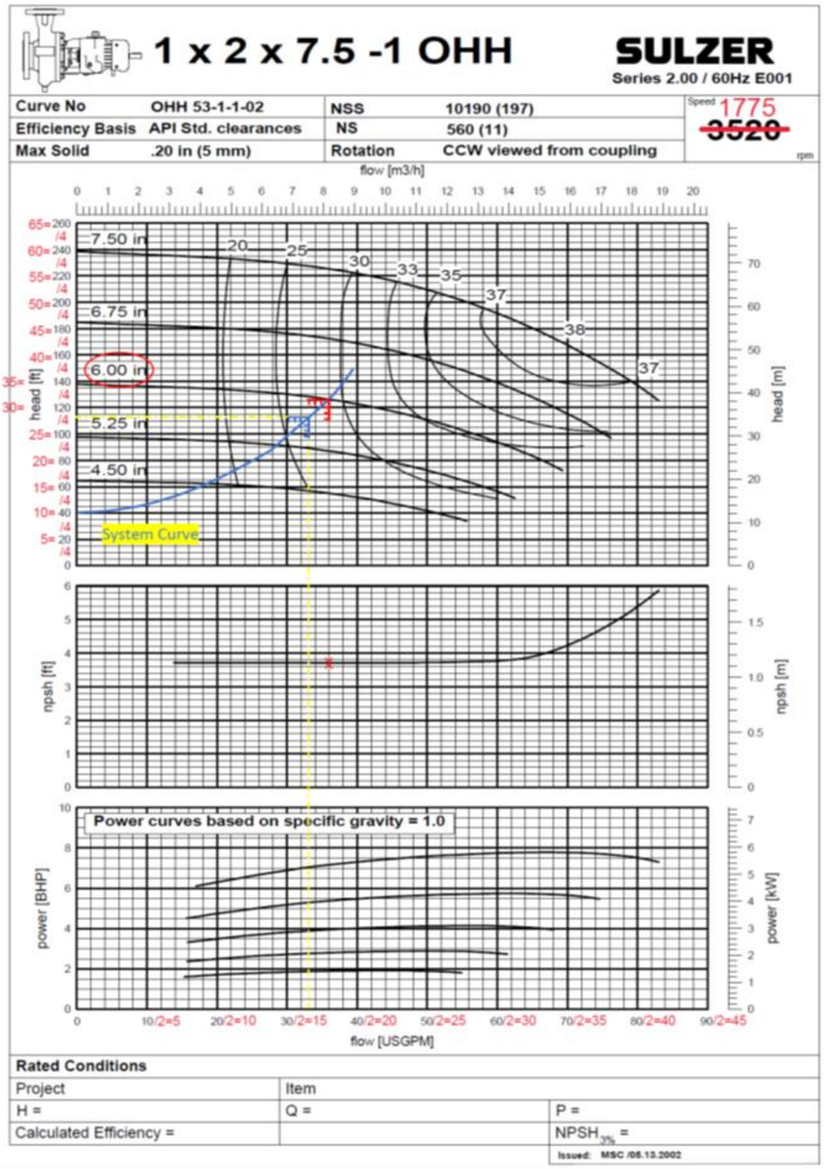


Figure 5-19 Pump #4 Curve

Procedure:
After referencing the curves and data from tables, use the below equations to solve for flow rate and select a pump that matches the previously calculated output.

$N_s = \frac{N\sqrt{Q}}{h^{\frac{3}{4}}}$ $\quad Power = \frac{\gamma Q h_A}{\eta}$ $\quad h_A = \Delta Z + \left(1 + f\left(\frac{L}{D}\right) + \Sigma k\right)\left(\frac{1}{2g}\right)\left(\frac{1}{A^2}\right)Q^2$

$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$ $\quad \frac{h_{a_1}}{h_{a_2}} = \left(\frac{N_1}{N_2}\right)^2$

$h_{a_1}/h_{a_2} = \left(\frac{N_1}{N_2}\right)^2$ $\quad \frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$

Calculations

Pump #1

$$Q = 0.139\frac{ft^3}{s} * \frac{7.48gal}{1ft^3} * \frac{60s}{1min} = 62.383gpm$$
$h_A = 25.7ft$
$\Delta Z = Rail\ Car\ Discharge\ Height - Storage\ Tank\ Height = 3ft - 15ft = 12ft$
Pipe Size = 1.5" SCH 40 NPS
Pump selected – 3 x 4 x 7.5 -1 OHH

Pump #2

$$Q = 0.018\frac{ft^3}{s} * \frac{7.48gal}{1ft^3} * \frac{60s}{1min} = 8.078gpm$$
$h_A = 43.2ft$
$\Delta Z = Storage\ Tank\ Discharge\ Height - Machining\ Tank\ Height = 0ft - 6ft = 6ft$
Pipe Size = 1.0" SCH 40 NPS
Pump selected – 1 x 3 x 11.5 -1 OHH

Pump #3

$$Q = 0.019\frac{ft^3}{s} * \frac{7.48gal}{1ft^3} * \frac{60s}{1min} = 8.527gpm$$
$h_A = 53.1ft$
$\Delta Z = Machining\ Tank\ Discharge\ Height - D.C. Storage\ Tank\ Height = 0ft - 10ft = 10ft$
Pipe Size = 0.5" SCH 40 NPS
Pump selected – 1 x 3 x 11.5 -1 OHH

Pump #4

$Q = 0.037\frac{ft^3}{s} * \frac{7.48gal}{1ft^3} * \frac{60s}{1min} = 16.606gpm$
$h_A = 28.2ft$
$\Delta Z = D.C. Storage\ Tank\ Discharge\ Height - Truck\ Tank\ Height = 0ft - 10ft = 10ft$
Pipe Size = 0.75" SCH 40 NPS
Pump selected – 1 x 2 x 7.5 -1 OHH

Summary:

The selections for pump 1-4 are, respectively.

Location	Pump Size
Pump - Railway to Railway Tank	3 x 4 x 7.5-1 OHH
Pump - Railway Tank to Machining	1 x3 x 11.5-1 OHH
Pump - Machining to Truck Tank	1 x 3 x 11.5-1 OHH
Pump - Truck Tank to Truck	1 x 2 x 7.5-1 OHH

Analysis:

After referring to the selection of pipes and pump type previously completed, the Sulzer pump catalog was used to specifically select a pump that corresponds with the calculated flow and head. Should an adjustment be made to the pipes, a decrease in pipe size would increase the pump head drastically, and if the pipe size were to increase, it can be assumed that the pump head would decrease further.

5.f.vi.04. Cavitation

Purpose:
Determine if the NPSH available is more than the NPSH required for each pump selected to operate in the designed system without cavitating

Design Considerations:
1. The Coolant is 60 °F.
2. The top level of the coolant in the Rail Car is 12ft above the ground.

Data & Variables:
Water Vapor Pressure at 60 °F = 0.2563 psia

From pump curves:
Pump #1 $NPSH_R = 5ft$
Pump #2 $NPSH_R = 3.4ft$
Pump #3 $NPSH_R = 3.4ft$
Pump #4 $NPSH_R = 3.7ft$

Procedure:
The energy losses before the pump and the pressure at the pump suction will be used to calculate the NPSH available.

Calculations:

$$\frac{P_{SUC} - P_V}{\gamma} = NPSH_A = \frac{P_1 - P_V}{\gamma} + (Z_1 - Z_{SUC}) - h_{L_{SUC}}$$

Pump #1
$NPSH_R = 5ft$
$(Z_1 - Z_{SUC}) = 12ft$
$h_{L_{SUC}} = 3.2ft$

$$NPSH_A = \frac{(14.7_{psia} - 0.2563_{psia})(144in^2/1ft^2)}{58.656\left(\frac{lb}{ft^3}\right)} + 12ft - 3.2ft = 44.259ft$$

Pump #2
$NPSH_R = 3.4ft$
$(Z_1 - Z_{SUC}) = 15ft$
$h_{L_{SUC}} = 1.475ft$

$$NPSH_A = \frac{(14.7_{psia} - 0.2563_{psia})(144in^2/1ft^2)}{58.656\left(\frac{lb}{ft^3}\right)} + 15ft - 1.475ft = 48.984ft$$

Pump #3
$NPSH_R = 3.4ft$
$(Z_1 - Z_{SUC}) = 6ft$
$h_{L_{SUC}} = 1.475ft$
$$NPSH_A = \frac{(14.7_{psia} - 0.2563_{psia})(144in^2/1ft^2)}{58.656\left(\frac{lb}{ft^3}\right)} + 6ft - 1.475ft = 39.984ft$$

Pump #4
$NPSH_R = 3.7ft$
$(Z_1 - Z_{SUC}) = 10ft$
$h_{L_{SUC}} = 5.703ft$
$$NPSH_A = \frac{(14.7_{psia} - 0.2563_{psia})(144in^2/1ft^2)}{58.656\left(\frac{lb}{ft^3}\right)} + 10ft - 5.703ft = 39.756ft$$

Summary:

Pump Location	$NPSH_R$ (ft)	$NPSH_A$ (ft)
Pump - Railway to Railway Tank	5.0	44.3
Pump - Railway Tank to Machining	3.4	49.0
Pump - Machining to Truck Tank	3.4	40.0
Pump - Truck Tank to Truck	3.7	39.8

The NPSH available is more than the NPSH required for each pump selected to operate in the designed system.

Analysis:
For the low flow rates and large tanks used in this system there is no risk of cavitation. The worst-case scenario of $NPSH_A$ will occur when the suction tanks are nearly empty. Even in this case, the $NPSH_A$ exceeds all $NPSH_R$ by more than the elevation of our tanks meaning that the pump will run dry before cavitation occurs.

5.f.vi.05. Summary of Selected Pumps

Purpose
Calculate the pump power and electrical motor power and then summarize all pump data.

Procedure
After applying affinity laws, use new pump operating point to calculate pump power and motor power requirements.

Calculations

Calculating Motor Power after applying Affinity Laws

- **Pump #1**

  New flow rate: $Q = 61.2gpm * \frac{1ft^3}{7.48gal} * \frac{1min}{60s} = 0.136\frac{ft^3}{s}$
  New Pump Head: $h_A = 25.2ft$
  Pump Efficiency: $e_m = 55\%$
  Specific Weight: $\lambda = 0.94 * 62.4\frac{lb}{ft^3} = 58.656\frac{lb}{ft^3}$

  $$Input\ Power = \frac{h_A \gamma Q}{e_m} = \frac{25ft * 58.656\left(\frac{lb}{ft^3}\right) * 0.136\left(\frac{ft^3}{s}\right)}{0.55} = 362.6\left(\frac{ft * lb}{s}\right)$$
  $$362.6\left(\frac{ft * lb}{s}\right) * \frac{1hp}{550\left(\frac{ft * lb}{s}\right)} = 0.66hp$$

- **Pump #2**

  New flow rate: $Q = 8.7gpm * \frac{1ft^3}{7.48gal} * \frac{1min}{60s} = 0.019\frac{ft^3}{s}$
  New Pump Head: $h_A = 46ft$
  Pump Efficiency: $e_m = 15\%$
  Specific Weight: $\lambda = 0.94 * 62.4\frac{lb}{ft^3} = 58.656\frac{lb}{ft^3}$

  $$Input\ Power = \frac{h_A \gamma Q}{e_m} = \frac{46ft * 58.656\left(\frac{lb}{ft^3}\right) * 0.019\left(\frac{ft^3}{s}\right)}{0.15} = 341.769\left(\frac{ft * lb}{s}\right)$$
  $$341.769\left(\frac{ft * lb}{s}\right) * \frac{1hp}{550\left(\frac{ft * lb}{s}\right)} = 0.62hp$$

- **Pump #3**

New flow rate: $Q = 8.7gpm * \frac{1ft^3}{7.48gal} * \frac{1min}{60s} = 0.019\frac{ft^3}{s}$
New Pump Head: $h_A = 57.3ft$
Pump Efficiency: $e_m = 15\%$
Specific Weight: $\lambda = 0.94 * 62.4\frac{lb}{ft^3} = 58.656\frac{lb}{ft^3}$

$$Input\ Power = \frac{h_A\gamma Q}{e_m} = \frac{57.3ft * 58.656\left(\frac{lb}{ft^3}\right) * 0.019\left(\frac{ft^3}{s}\right)}{0.15} = 425.725\left(\frac{ft * lb}{s}\right)$$

$$425.725\left(\frac{ft * lb}{s}\right) * \frac{1hp}{550\left(\frac{ft * lb}{s}\right)} = 0.77hp$$

- **Pump #4**

New flow rate: $Q = 18gpm * \frac{1ft^3}{7.48gal} * \frac{1min}{60s} = 0.04\frac{ft^3}{s}$
New Pump Head: $h_A = 31.25ft$
Pump Efficiency: $e_m = 28\%$
Specific Weight: $\lambda = 0.94 * 62.4\frac{lb}{ft^3} = 58.656\frac{lb}{ft^3}$

$$Input\ Power = \frac{h_A\gamma Q}{e_m} = \frac{31.25ft * 58.656\left(\frac{lb}{ft^3}\right) * 0.04\left(\frac{ft^3}{s}\right)}{0.28} = 261.857\left(\frac{ft * lb}{s}\right)$$

$$261.857\left(\frac{ft * lb}{s}\right) * \frac{1hp}{550\left(\frac{ft * lb}{s}\right)} = 0.48hp$$

Summary

Table 5-14 Summarized Pump Data

Location	Pump Size	Pump Head (ft)	Pump Flow (gpm)	RPM	$NPSH_R$ (ft)
Pump - Railway to Railway Tank	3 x 4 x 7.5-1 OHH	25.2	61.2	1170	5
Pump - Railway Tank to Machining	1 x3 x 11.5-1 OHH	46.0	8.7	1170	3.4
Pump - Machining to Truck Tank	1 x 3 x 11.5-1 OHH	57.3	8.7	1170	3.4
Pump - Truck Tank to Truck	1 x 2 x 7.5-1 OHH	32.3	18.0	1775	3.7

Location	Impeller Size (in)	Efficiency	Pump Power (hp)	Motor Power (hp)	Pump Weight (lb)
Pump - Railway to Railway Tank	7.50	0.55	0.66	0.73	352
Pump - Railway Tank to Machining	9.75	0.15	0.62	0.68	514
Pump - Machining to Truck Tank	10.88	0.15	0.77	0.85	514
Pump - Truck Tank to Truck	6.00	0.28	0.48	0.53	311

Analysis

To achieve the target flow rates and pump heads the affinity laws were used to adjust the Sulzer catalog pump curves appropriately. The speeds of all pumps were reduced, and impellers machined to custom sizes to accommodate the system requirements.

5.f.vii. Instrumentation Selection

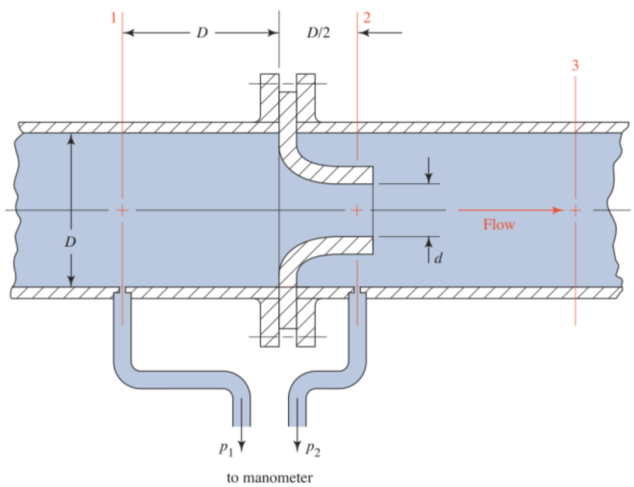
5.f.vii.01. Flow Rate and Pressure Drop

Purpose

Select instrumentation to read the flow rate through one of the pipelines.

Drawing:

Table 5-15 Dimensions of Flow Nozzle style Flowmeter



Data and Variables

For 1.0" NPS pipeline from the railway tank to machining:

v	= 3.09 ft/s	; From section 5.f.ii
D_1	= 0.0874 ft	; From section 5.f.ii
A_1	= 0.006 ft^2	; From section 5.f.ii
sg_{hg}	= 13.6	; Specific gravity of mercury
$sg_{coolant}$	= 0.94	; Specific gravity of coolant
N_R	= 10168	; Reynolds # from section 5.f.v

Procedure

A flow nozzle is selected as the flow measuring device. The d/D ratio is selected as 0.6 and the manometer fluid is mercury.

Solve for the discharge coefficient, C, using the flow nozzle equation:

$$C = 0.9975 - 6.53\sqrt{\beta/N_R}$$

Rearrange the flow equation to solve for h, manometer height:

$$v_1 = C\sqrt{\frac{2gh\left[\left(\frac{\gamma_m}{\gamma_f}\right)-1\right]}{\left(\frac{A_1}{A_2}\right)^2-1}}$$

$$h = \frac{\left(\frac{v_1^2}{C}\right)*\left(\left(\frac{A_1}{A_2}\right)^2-1\right)}{2g\left(\left(\frac{\gamma_m}{\gamma_f}\right)-1\right)}$$

<u>Calculations</u>
For the 1.0" DN pipeline:

$$C = 0.9975 - 6.53\sqrt{\frac{\beta}{N_R}} = 0.9975 - 6.53\sqrt{\frac{0.6}{10168}} = 0.947$$

$C = 0.947$

$A_2 = \frac{\pi}{4}(0.6 * D_2)^2 = 0.00216\, ft^2$

$$h = \frac{\left(\frac{\left(3.09\frac{ft}{s}\right)^2}{0.947}\right)*\left(\left(\frac{0.006\, ft^2}{0.0022\, ft^2}\right)^2-1\right)}{2\left(32.2\frac{ft}{s^2}\right)\left(\left(\frac{13.6}{0.94}\right)-1\right)} = 0.078\, ft$$

$h = 0.078\, ft * 12in = 0.94\, inHg$

<u>Summary</u>
The diameter of the flow nozzle is 0.6 times the diameter of the pipeline. The flow area of the flow nozzle is 0.00216 ft^2. Using mercury as the manometer fluid, the manometer height will read 0.94" when the fluid velocity is at design velocity of 3.09 ft/s.

<u>Analysis</u>
The expected manometer height for a flowmeter with d/D ratio of 0.6 is 0.94". The required height of the manometer can be decreased by decreasing d/D ratio although this will result in a higher discharge coefficient and more losses. The flow rate can be calculated by multiplying the measured velocity by the known pipe flow area.

6. Final Drawings

6.a. Plot Plan

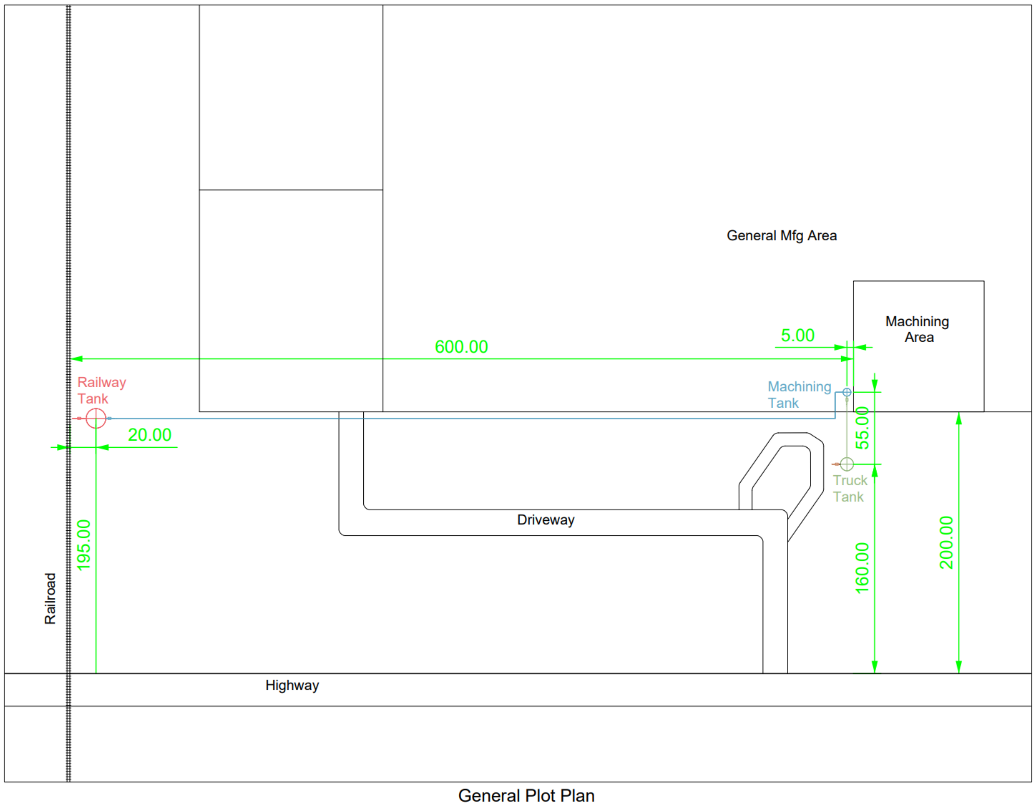


Figure 6-1 Plot Plan

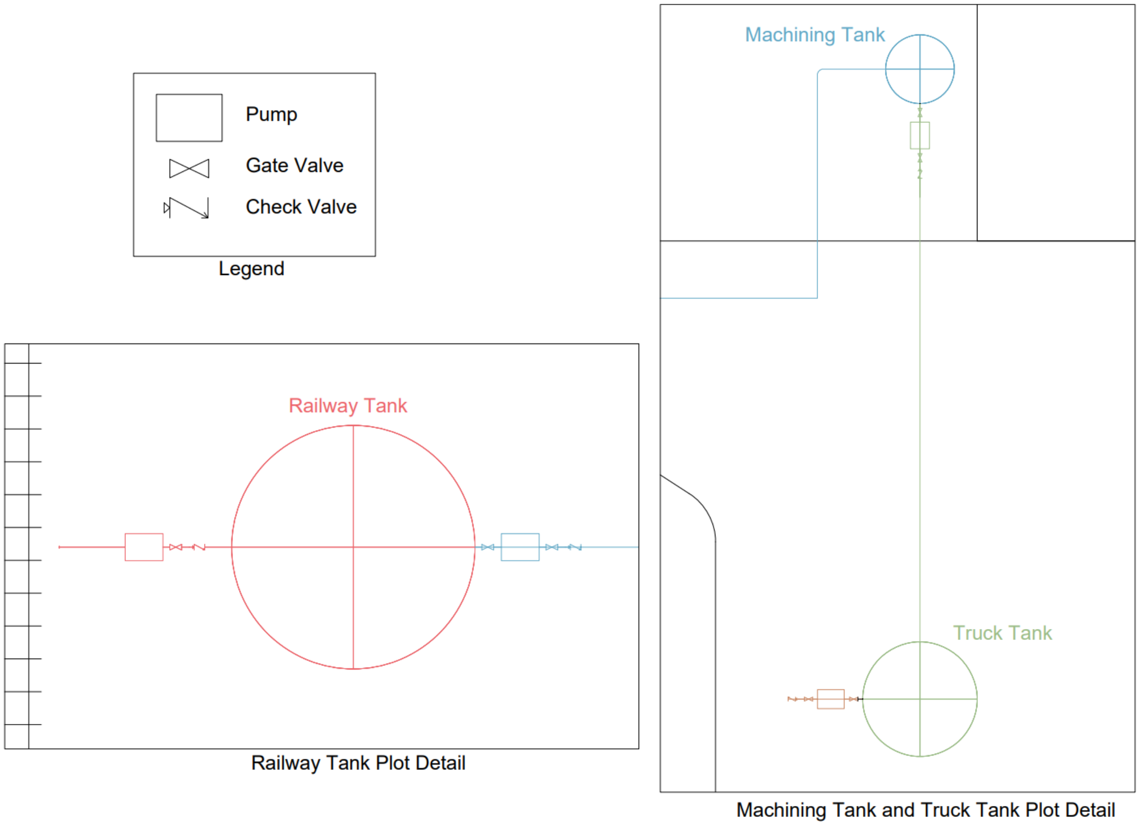
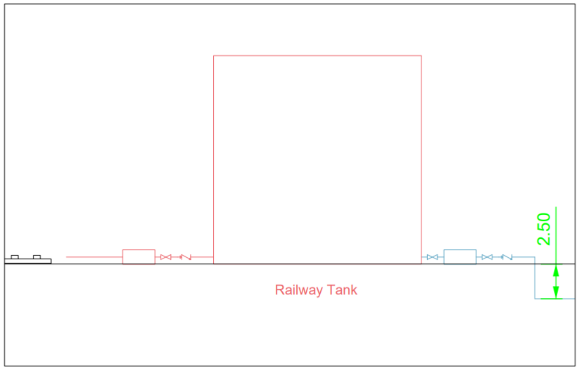
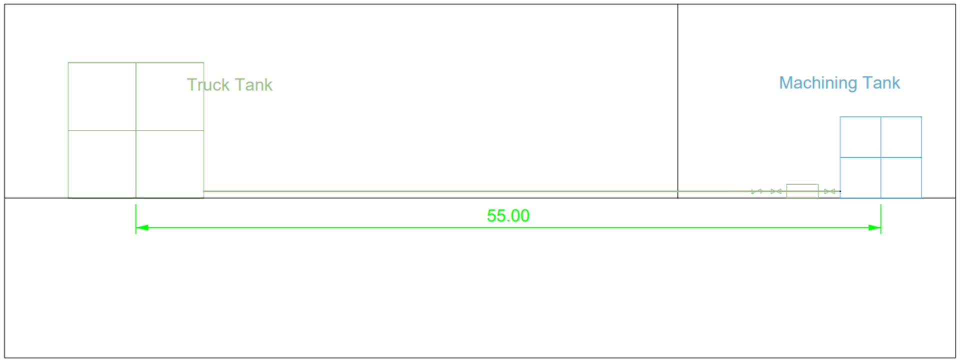


Figure 6-2 Plot Plan Details

6.b. Elevations

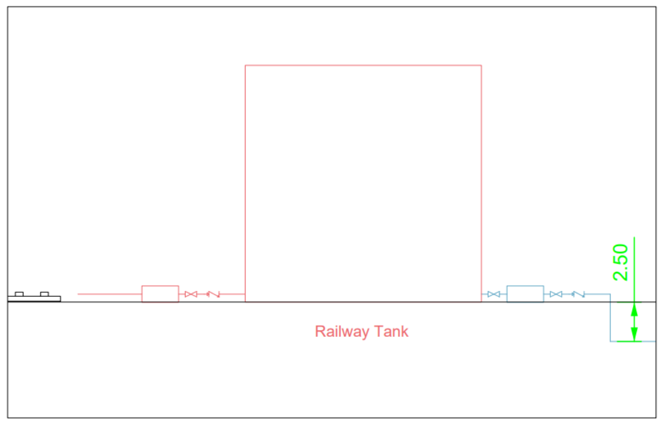


Railway Tank Elevation

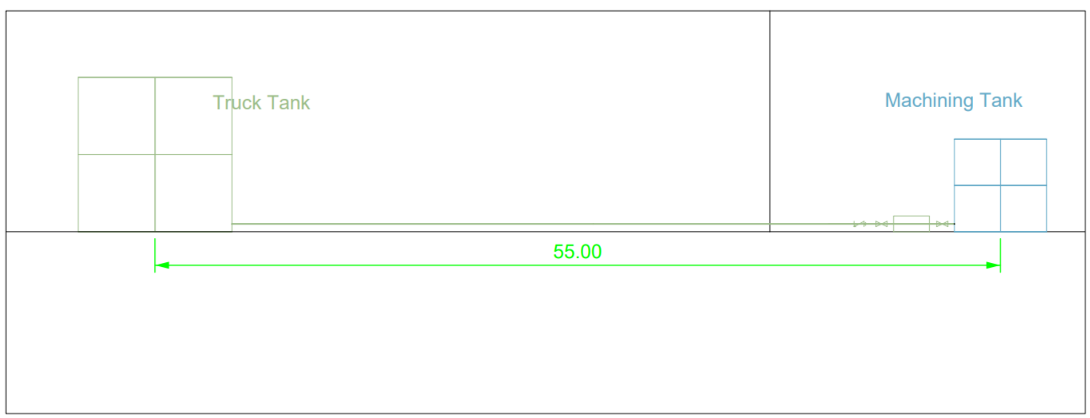


Machining Tank and Truck Tank Elevation

Figure 6-3 Elevation Drawings



Railway Tank Elevation



Machining Tank and Truck Tank Elevation

Figure 6-4 Elevation Drawings

6.c. Isometric

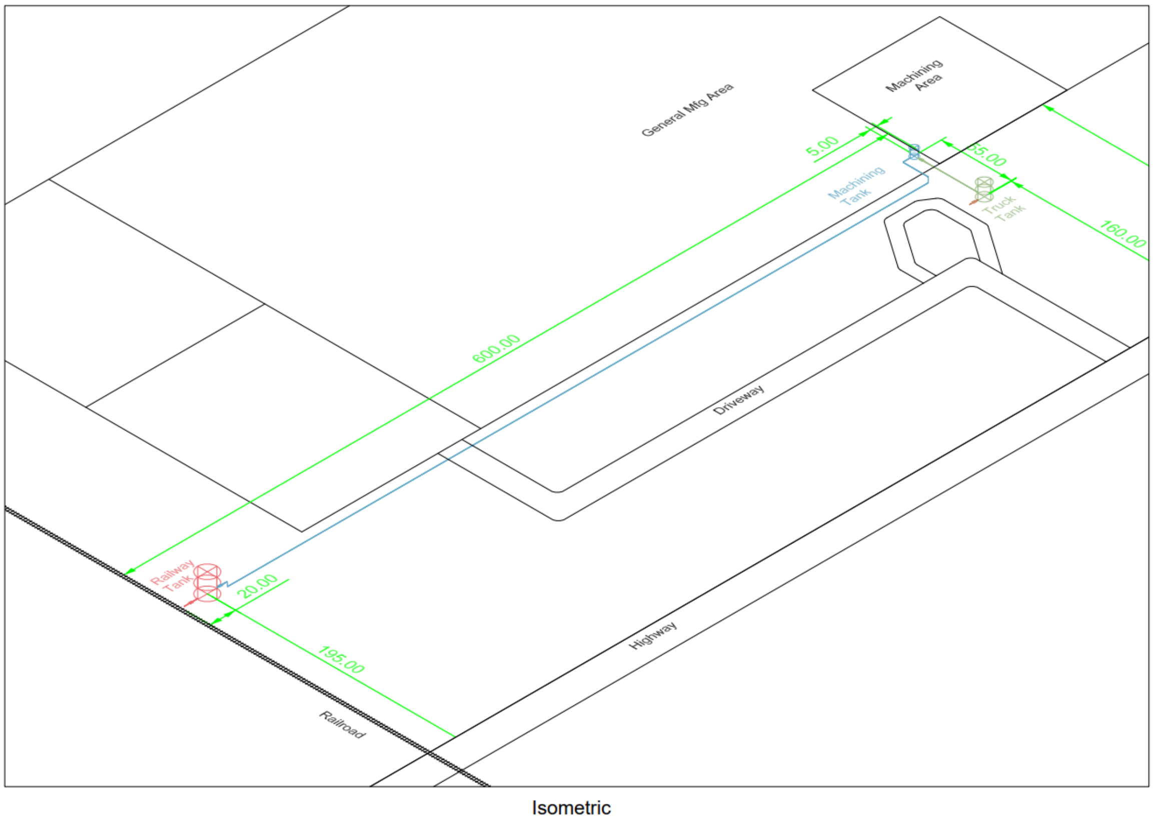


Figure 6-5 Isometric Drawing

7. Bill of Materials and Equipment List

Table 7-1 Bill of Materials

Part Name	Part Number	Unit/Length	Estimate Cost
Pipes			
Schedule 40 steel pipe	½ inch pipe	10.5 feet	$59.41
Schedule 40 steel pipe	¾ inch pipe	45.5 feet	$135.82
Schedule 40 steel pipe	1 inch pipe	6.5 feet	$19.46
Schedule 40 steel pipe	1 ½ inch pipe	590.6 feet	$2,355.51
Fittings			
4-foot Flex Hose	1 ½ inch pipe	1	$211.38
Gate Valve	1 ½ inch pipe	1	$273.84
Check Valve	1 ½ inch pipe	1	$332.77
Gate Valve	1 inch pipe	1	$151.82
Check Valve	1 inch pipe	1	$223.42
90-degree elbow	1 inch pipe	5	$40.80
Gate Valve	½ inch pipe	3	$307.38
Check Valve	½ inch pipe	1	$157.77
Gate Valve	¾ inch pipe	2	$242.16
Check Valve	¾ inch pipe	1	$175.38
Tanks			
Rail Tank	15’ D x 15’ H	1	$7,429.00
Storage Tank	6.0’ D x 6.0’ H	1	$12,886.73
Dirty coolant	10’ D x 10’ H	1	$28,878.05
Pumps			
Pump 1 - Railcar to Big Storage	3 x 4 x 7.5 -1 OHH	1	$5,000.00
Pump 2 - Big Storage to Machine Reservoir	1 x 3 x 11.5 -1 OHH	1	$5,000.00
Pump 3 - Machine Reservoir to Dirty Coolant	1 x 3 x 11.5 -1 OHH	1	$5,000.00
Pump 4 - Dirty Coolant to Truck	1 x 2 x 7.5 -1 OHH	1	$5,000.00
Motor			
1170 RPM Motor	60 Hz	3	$5,115.00
1775 RPM Motor	60 Hz	1	$2,463.08
		Total Est.	$81,458.77

Note: Cost is an estimate only and was not specifically requested by the client. It is being provided as a convenience for budgetary estimating purposes.

8. Final Remarks

While minimizing cost was not a key focus of the design outlined in this project, the design presented does not contain any waste and could easily be modified to reduce procurement costs. The fundamental design uses standard dimension above ground storage tanks which are easy to procure, and a pipeline optimized to reduce length and friction losses. The longest section of the pipeline is buried beneath the frost line to save the client the cost of pipe supports and insulation. Stainless steel was selected as the pipeline and tank material due to corrosion resistance, but the client can choose to investigate procuring PVC pipes and tanks instead to greatly reduce cost. Water hammer calculations will need to be redone in this case to confirm that the new material is not at risk of fracturing.

The clients' requirements are thus summarized and re-confirmed below. The client needs to unload coolant by 15000-gallon railcar, store it in a 1000-gallon reservoir for machining, drain it to an intermediate storage tank, and take away the dirty fluid by truck once per month. The dirty coolant exchange between machining and intermediate storage must occur within one 8-hour shift. The design provided satisfies all minimum holding tank requirements and flow rates as designated by the client and will allow for a full exchange of dirty coolant in the machining tank in a 4-hour period.

The client specified that only one tank can be inside the plant and that the coolant used is at risk of freezing. The machining tank was thus located inside of the factory and the longest pipeline section buried below the frost line. The client requested only Sulzer pumps were used, thus only Sulzer pumps were selected.

The client asked us to provide additional analysis regarding blind flanges, open channels, and flow meters. All the requested information was calculated and included in this report. The design was checked for pipe thickness, wall tank thickness, water hammer, and cavitation. All common pipeline failure modes were proven not at risk based on the provided calculations. All necessary info was calculated and provided for use by civil and electrical engineers in finalizing design. This includes pipe supports, wind loads, and electrical motor requirements. Finally, drawings and a bill of materials were provided for use in advancing this preliminary project into construction.

Should the client have any questions or concerns regarding the content of this project please do not hesitate to contact us.

Sincerely.

The 5ive Consulting

9. Appendix

Average Mechanical Properties of Typical Engineering Materials[a]

(U.S. Customary Units)

Materials		Specific Weight (lb/in³)	Moduls of Elasticity E (10^3) ksi	Modulus of Rigidity G (10^3) ksi	Yield Strength (ksi) σ_Y Tens.	Comp.[b]	Shear	Ultimate Strength (ksi) σ_u Tens.	Comp.[b]	Shear	%Elongation in 2 in. specimen	Poisson's Ratio ν	Coef. of Therm. Expansion α (10^{-6})/°F
Metallic													
Aluminum Wrought Alloys	2014-T6	0.101	10.6	3.9	60	60	25	68	68	42	10	0.35	12.8
	6061-T6	0.098	10.0	3.7	37	37	19	42	42	27	12	0.35	13.1
Cast Iron Alloys	Gray ASTM 20	0.260	10.0	3.9	–	–	–	26	96	–	0.6	0.28	6.70
	Malleable ASTM A-197	0.263	25.0	9.8	–	–	–	40	83	–	5	0.28	6.60
Copper Alloys	Red Brass C83400	0.316	14.6	5.4	11.4	11.4	–	35	35	–	35	0.35	9.80
	Bronze C86100	0.319	15.0	5.6	50	50	–	35	35	–	20	0.34	9.60
Magnesium Alloy	[Am 1004-T61]	0.066	6.48	2.5	22	22	–	40	40	22	1	0.30	14.3
Steel Alloys	Structural A-36	0.284	29.0	11.0	36	36	–	58	58	–	30	0.32	6.60
	Structural A992	0.284	29.0	11.0	50	50	–	65	65	–	30	0.32	6.60
	Stainless 304	0.284	28.0	11.0	30	30	–	75	75	–	40	0.27	9.60
	Tool L2	0.295	29.0	11.0	102	102	–	116	116	–	22	0.32	6.50
Titanium Alloy	[Ti-6Al-4V]	0.160	17.4	6.4	134	134	–	145	145	–	16	0.36	5.20
Nonmetallic													
Concrete	Low Strength	0.086	3.20	–	–	–	1.8	–	–	–	–	0.15	6.0
	High Strength	0.086	4.20	–	–	–	5.5	–	–	–	–	0.15	6.0
Plastic Reinforced	Kevlar 49	0.0524	19.0	–	–	–	–	104	70	10.2	2.8	0.34	–
	30% Glass	0.0524	10.5	–	–	–	–	13	19	–	–	0.34	–
Wood Select Structural Grade	Douglas Fir	0.017	1.90	–	–	–	–	0.30[c]	3.78[d]	0.90[d]	–	0.29[c]	–
	White Spruce	0.130	1.40	–	–	–	–	0.36[c]	5.18[d]	0.97[d]	–	0.31[c]	–

Figure 9-1 Average Mechanical Properties of Typical Engineering Materials

Seamless	1.00
Electric resistance welded	1.00
Furnace butt welded	.60
Seamless	1.00
Seamless	1.00
Electric resistance welded	1.00
Double submerged arc welded	1.00
Electric-fusion-welded	1.00
Electric-fusion-welded	1.00
Electric-fusion-welded	1.00
Seamless	1.00
Electric resistance welded	1.00
Electric flash welded	1.00
Submerged arc welded	1.00
Furnace butt welded	.60
Pipe over 4 inches (102 millimeters)	.80
Pipe 4 inches (102 millimeters) or less	.60

Figure 9-2 Longitudinal Joint Quality Factor from 49 CFR Subpart E

Coefficient Y						
Material	Temperature (^{o}F)					
	< 900	950	1000	1050	1100	> 1150
Ferritic steels	0.4	0.5	0.7	0.7	0.7	0.7
Autenitic steel	0.4	0.4	0.4	0.4	0.5	0.7
Other ductile materials	0.4	0.4	0.4	0.4	0.4	
Cast iron	0.0					

Figure 9-3 ASME 31.3 Piping Materials Wall Thickness Coefficient

TABLE F.1 Schedule 40

Nominal Pipe Size		Outside Diameter		Wall Thickness		Inside Diameter			Flow Area	
NPS (in)	DN (mm)	(in)	(mm)	(in)	(mm)	(in)	(ft)	(mm)	(ft^2)	(m^2)
⅛	6	0.405	10.3	0.068	1.73	0.269	0.0224	6.8	0.000 394	3.660×10^{-5}
¼	8	0.540	13.7	0.088	2.24	0.364	0.0303	9.2	0.000 723	6.717×10^{-5}
⅜	10	0.675	17.1	0.091	2.31	0.493	0.0411	12.5	0.001 33	1.236×10^{-4}
½	15	0.840	21.3	0.109	2.77	0.622	0.0518	15.8	0.002 11	1.960×10^{-4}
¾	20	1.050	26.7	0.113	2.87	0.824	0.0687	20.9	0.003 70	3.437×10^{-4}
1	25	1.315	33.4	0.133	3.38	1.049	0.0874	26.6	0.006 00	5.574×10^{-4}
1¼	32	1.660	42.2	0.140	3.56	1.380	0.1150	35.1	0.010 39	9.653×10^{-4}
1½	40	1.900	48.3	0.145	3.68	1.610	0.1342	40.9	0.014 14	1.314×10^{-3}
2	50	2.375	60.3	0.154	3.91	2.067	0.1723	52.5	0.023 33	2.168×10^{-3}
2½	65	2.875	73.0	0.203	5.16	2.469	0.2058	62.7	0.033 26	3.090×10^{-3}
3	80	3.500	88.9	0.216	5.49	3.068	0.2557	77.9	0.051 32	4.768×10^{-3}
3½	90	4.000	101.6	0.226	5.74	3.548	0.2957	90.1	0.068 68	6.381×10^{-3}
4	100	4.500	114.3	0.237	6.02	4.026	0.3355	102.3	0.088 40	8.213×10^{-3}
5	125	5.563	141.3	0.258	6.55	5.047	0.4206	128.2	0.139 0	1.291×10^{-2}
6	150	6.625	168.3	0.280	7.11	6.065	0.5054	154.1	0.200 6	1.864×10^{-2}
8	200	8.625	219.1	0.322	8.18	7.981	0.6651	202.7	0.347 2	3.226×10^{-2}
10	250	10.750	273.1	0.365	9.27	10.020	0.8350	254.5	0.547 9	5.090×10^{-2}
12	300	12.750	323.9	0.406	10.31	11.938	0.9948	303.2	0.777 1	7.219×10^{-2}
14	350	14.000	355.6	0.437	11.10	13.126	1.094	333.4	0.939 6	8.729×10^{-2}
16	400	16.000	406.4	0.500	12.70	15.000	1.250	381.0	1.227	0.1140
18	450	18.000	457.2	0.562	14.27	16.876	1.406	428.7	1.553	0.1443
20	500	20.000	508.0	0.593	15.06	18.814	1.568	477.9	1.931	0.1794
24	600	24.000	609.6	0.687	17.45	22.626	1.886	574.7	2.792	0.2594

Figure 9-4 Typical Dimensions of SCH 40 Steel Pipe

10. Self-Reflection

Devon Kigler

I believe that the experience of this project, and every sub-topic of fluid mechanics that is explored throughout the duration of this project, are extremely beneficial to my professional career. Understanding how to complete a project reminiscent of a real-world situation was a new experience, and it felt necessary for me to further my skill set.

This class is essential in the sense that it gives you skills that will be used every day in an engineer's professional career. The project emphasizes collaboration in a way that induces professionalism and brings those qualities out in those who complete it.

In this project, I functioned as an organizer, as well as a collaborator. I completed tasks involved with pipeline systems and energy losses, and took in others work to format, proofread, and display their work in a way that comes across as professional. This role worked well for me as I am not as adept or experienced as my teammates, and it allowed me to learn and produce satisfactory work without altering the project's timeline. I feel grateful for my team and the project that we have been able to produce, and do not feel as if there are any notable flaws in our work.

If I were to be able to send a message to myself before I started this class, I would tell myself to be less anxious to reach out for help in concepts that I struggled to grasp. Professor Ayala has an excellent history of being available and willing for his students, and I could have had greater benefit from that fact.

Brynn Jewell

The Pipeline Project is the closest we will get to a real-world assignment or project. As such it is an excellent candidate for a portfolio to show experience in a professional career. The projects key focuses highlight working in a team atmosphere where you need to trust and collaborate with your teammates or in this case fellow students. It is an exercise in writing a professional document, at a level and length present on an actual job. Due to this a level of organization higher than that seen at a college, bordering on a professional, level is needed. Because the project is fulfilled from beginning to end it is an excellent learning opportunity for a professional career. The skills acquired and practiced throughout the project are extremely important in professional settings as well as out. The overarching ability to work in a team setting, learn and adapt to the strengths and weaknesses of your team, are a demand in almost every job and many settings in day-to-day life. This specific project and format is useful in engineering environments as many projects are laid out in this way, learning, creating and adjusting systems, whether it is in design, redesign or fabrication.

As a personal collaborator in this project, I took the lead on many heavy calculations section, such as energy losses and support systems. I took these on or was assigned them because they required heavy research on calculations or organization in the work. I also offered occasional collaboration or observation on additional calculations throughout the project with team members. I often had trouble keeping up with such an experienced team as they had past understanding of engineering at a professional setting and the level of execution needed, as the project progressed my grasp and execution improved, in attempt to match theirs. In addition, it took communication with the team leader and other members due to the nature of my schedule as a student with many additional responsibilities and demands on my time. With improved collaboration we were able to work so it had limited affect on my own work as well as that of the team.

If this semester was restarted with what we know now, I would advocate for better allocation or the work throughout the semester. At the beginning of the semester, we were putting between 10-20 hr. a week into the class and project and towards the end only a few hours a week or month on just the project. With a crunch here at the end which is unavoidable. To have a more successful final project this time could be more spread out as I felt the beginning of the project was to rush and my work and those of my team was not as effective as it could have been. When reaching the end of the project this became apparent as we needed to return to previous calculations and reassess them. With all of this under consideration I believe we were very successful individually and as a team.

Nick Agreste

The coolant design project was absolutely influential and something that I will remember years from now as the most detailed school project I've ever worked on. I wholeheartedly believe that the techniques and concepts learned in this class will stick with me for the rest of my career. I expect to continue working in manufacturing engineering where fluid dynamics is ever-present.

I would describe this project as a start to finish pipeline design, where my group was given a scope and then given all the freedom to transform our ideas into a final design that satisfies the client's requirements. My role in the project was as project manager, meaning that I was ultimately accountable for the quality and timeliness of the group's work.

My strengths were having prior industry exposure, strong technical writing skills, and good people skills. I used these strengths to bolster the team by assigning and reviewing tasks as a group according to my team members strengths, and then used my industry experience to review and improve the output of my team member's work. I feel that I was able to help the team define a vision for what we wanted the final project to look like and then use my skillset to course correct us towards that vision.

My weaknesses were lack of knowledge of fluid mechanics and a historical tendency to try and do everything myself. The classroom syllabus taught me everything I need to know about fluid mechanics, and I was able to address my tendency to overwork by setting firm deadlines with team members on which parts of the project they would do and being clear on what was in each team member's scope.

Our project features a simple, robust design with no bells and whistles. The pipes are sized according to critical velocity and minimizing losses. The fittings are selected according to a typical layout of valve->pump->valve->check. The calculations are all correct and every team member can say that they contributed to different parts of the project. The only weaknesses I see in our design are that the material selection for the tanks and pipes is likely overkill since we were not asked to minimize cost.
If I were to start the class over again, the only advice I would give myself would be to 'get ready to have a fun semester'. I thoroughly enjoyed the class and my team and know that in addition to performing well in the class my team has produced a high-quality final project.

Edwin Albertinie

As a mechanical technician in a rum distillery this engineering project for designing a full pipeline system of a manufacturing plant for Continental AG didn't seem very foreign at first. However, this course and project proved to me that regardless of familiarity with most of the terms and having experienced some the phenomenon, for example cavitation, that I knew very little when it came to the application of Fluid Mechanics in engineering.

My group members and I worked diligently to ensure the successful culmination of this project whilst also creating comfortable work setting. It was easy to discuss ideas and make decisions amongst each other.

Having the project tasks spread throughout the semester and enabling the group to apply the class content to the project requirements placed everything into better perspective and will aid in the application of this knowledge to my career.

My biggest take away from this course is pump selection as the final step in the system design. It sounds obvious now that it should be last, and even stupid to think otherwise. Before this course I thought the pump was chosen to match a desired flow rate and I considered pump head only for elevation and I had never heard of energy losses in a pipeline. I remember being focused on the pumps very early in the project, but with knowledge I have acquired I now know better.