Old Dominion University

MET 330 Design Project DRAFT

Continental AG

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Abstract

Continental AG is planning to build a new manufacturing facility in Dayton, Ohio. As part of this plant there will be an automated machining area inside the main building. This area will require coolant for the machines to prevent damage to the tools or the parts. This will be done via a 1000-gallon coolant tank located inside the machining area. The dirty coolant from the 1000-gallon tank will be emptied every week. This dirty coolant will be moved to a 15000-gallon holding tank where it will await removal by semi-trailer. Clean coolant will be supplied to the 1000-gallon tank by a 15000-gallon tank that will be filled by a railcar when empty. The project covers the selection, placement, and layout of all components in this fluid transfer system except for the lines bringing coolant to the machines.

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3. Project

3.1. Site Location

The new manufacturing facility is to be located in Dayton Ohio, exact location TBD.

Latitude: 35.76° N Longitude: 84.19° W (approximate)

The machining area will be located within the building, 600 feet from the railroad and 200 feet from the highway. The machining area is located along the front side of the building and is a 100-foot square. The ceiling will be 32 feet high and the building will be one single story. The driveway is located on the front of the building to the west side of the building. Temperatures in the area may dip below freezing for extended periods, outdoor tanks should be designed to withstand this, the frost level is 30 inches below ground level.

3.2. Design Philosophy

The system was engineered in such a way that there are as few points of failure as possible. For this reason, gravity is used instead of pumps wherever possible. This reduces the need for pumps which require more maintenance and will fail more often than a system with no pumps. In addition, the system was designed with future maintenance in mind. Cutoff valves were placed wherever necessary to facilitate work without the need to drain any of the tanks. Another high priority was the quick and efficient transfer of fluid such that it interfered with regular productivity of the plant as little as possible. This meant quick fluid transfer times. The clean coolant storage tank was made to be 15000-gallons, the same size as a typical coolant delivery. The dirty coolant tank is also 8,000 gallons. This was done so that if for some reason (inclement weather for example) the recycling trucks are unable to pick up the coolant, the plant can continue to operate for an extended period before the tank fills completely and halts production.

All calculations were made using the cold standard, a temperature of 32 degrees Fahrenheit, and atmospheric pressure of 14.7psia. The coolant in question is a solution of water and soluble oil with a specific gravity of 0.94 and a freezing point of 0 degrees Fahrenheit. Its corrosiveness is the same as that of water. In addition, the coolant's vapor pressure and viscosity are 1.5 times that of water.

3.3. Sources

Mott, R. L., & Untener, J. A. (2015). *Applied Fluid Mechanics.* Upper Saddle River : Pearson Education Inc.
.

Sulzer Ltd. (2002, October). Sulzer Type OHH. Winterthur, Switzerland .

3.4. Materials and Specifications

Materials selected for the system are based on heavy duty commercial applications. Long life and cost are the primary concerns in this system. All selected pipes are based on NPS Schedule 40 pipe sizing for ease of design and interoperability with future upgrades. All pumps are Sulzer OHH type. The system layout was designed in such a way as to balance minimal pipe length with ease of future maintenance. Pumps will be supplied by Sulzer, and piping suppliers may be selected by the contractor so long as they satisfy the minimum design requirements. Both the clean coolant storage tank and dirty coolant tanks are located outside of the facility to reduce intrusiveness of the system. The clean coolant will be located underground between the building and the railroad tracks and the dirty coolant tank will be located above ground with the top of the tank even with the roof of the facility. In the event of a failure in or near tank 3, the tank may be drained without a truck present as an open channel is present to remove the coolant from the immediate area. This open channel was designed with a very shallow depth so that most factory equipment would be able to drive right over it without the need for paths over it.

3.4.1. Pipe and tank material

All pipes and tanks will be made from the same material wherever possible. That material will be ASTM A106 steel. This material was chosen for its combination of strength and cost. In addition, it is very weldable which will make installation easier and will positively impact the strength and longevity of all welded joints.

3.4.2. Fluid Characteristics

The coolant is a solution of water and soluble oil with a specific gravity of 0.94 and a freezing point of 0 degrees Fahrenheit. It’s dynamic and kinematic viscosity are 1.5 times those of water. Its corrosiveness is similar to that of water.

3.5. Preliminary Drawings and Sketches

3.5.1. Plot Plan

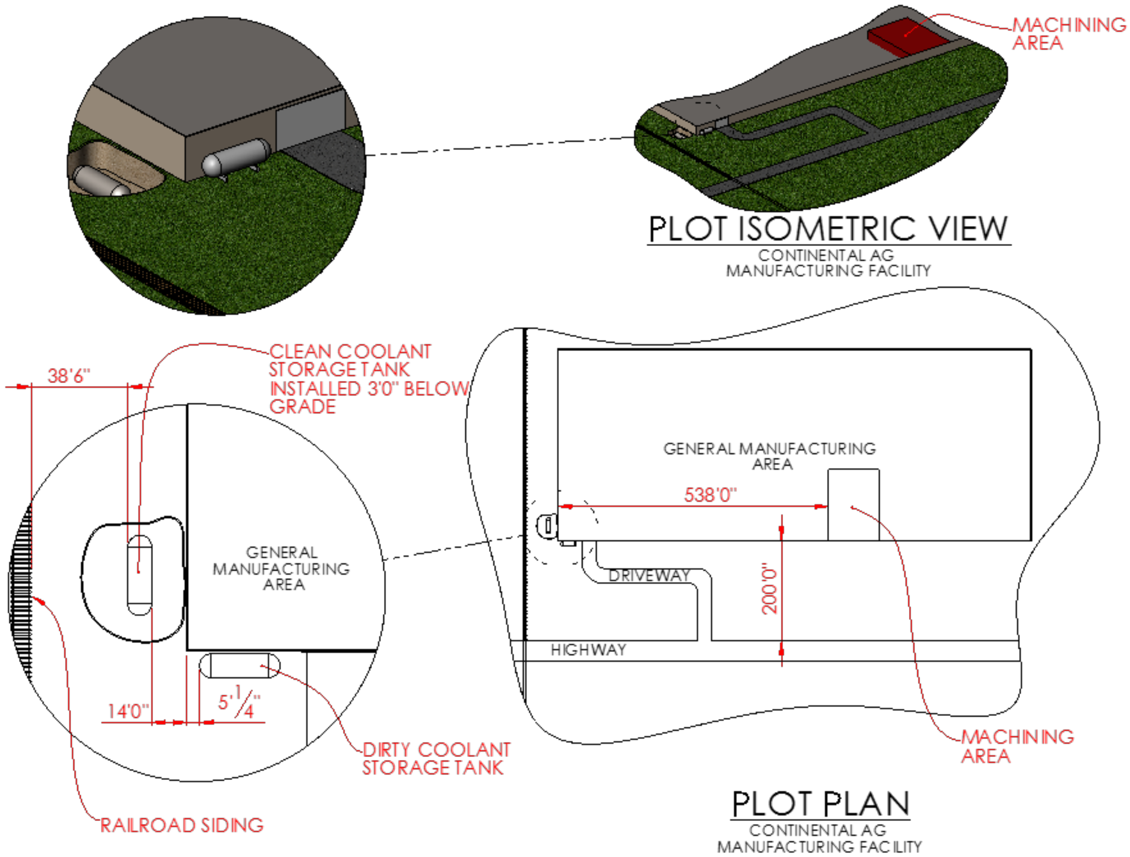


Figure 3.5.1

3.6. Design Calculations

3.6.1. Tank Specifications

3.6.1.1. Location

Tank 1, the clean coolant tank, is to be located underground with the top of the tank 36 inches below the surface. It will be located between the facility and the railroad, 14 feet from the building and 38 feet 6 inches from the railroad.

Tank 2, the working coolant tank, will be located inside the machining area justified in the southwest corner on the floor of the facility with enough room for work to be done on it and the pump easily without taking up too much space on the floor.

Tank 3, the dirty coolant tank, will be located above ground along the front of the building to facilitate drainage of the tank without the use of a pump. The top of the tank will be roughly located even with the roof of the facility at 32 feet above ground and it will in line with the corner of the building, and 5 and ¾ feet from the front wall.

3.6.1.2. Size Design

Tank 1 (clean coolant) will be cylindrical with hemispherical ends. The tank will be nominally 15000 gallons with a length (excluding the hemispheres) of 30 feet and an outer diameter of 118.875 inches.

Tank 2 (working coolant) will be 1000 gallons nominally. The tank will be a cylinder mounted vertically with a height of 11 feet and an outer diameter of 48.875 inches.

Tank 3 (dirty coolant) will be 8000 gallons nominally. It will be a cylindrical tank with hemispherical ends and a length (excluding the hemispheres) of 13.6 feet.

3.6.1.3. Tank Thickness

1. Purpose
   a. To determine wall thickness and material type for storage tanks (T1, T2 and T3).
2. Drawings and Diagrams

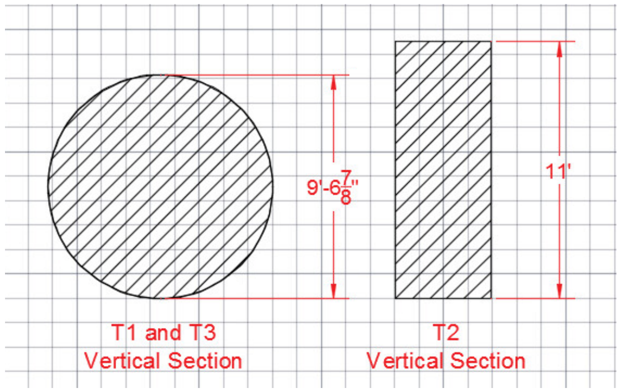


Figure 3.6.1.3

3. Design Considerations
   a. T1 and T3
      i. The tank will be located outdoors.
      ii. Tank will be stationary while containing coolant.
      iii. Tank outside diameter on vertical section is the critical dimension for sizing tank wall thickness.
      iv. Both tanks have the same vertical dimensions.
   b. T2
      i. The tank will be located indoors.
      ii. Tank will be stationary while containing coolant.
      iii. Tank overall height will be the critical dimension for sizing tank tall thickness.
4. Data
   a. T1 and T3
      Elongated cylinder Style tanks
   b. T2
      Standard cylinder style tank.
   c. Material Properties
      i. Allowable stress for Steel ASTM A106 s= 20000 lbf/in^2
      ii. Longitudinal joint quality factor E = 1
      iii. Correction factor y = .4
      iv. Corrosion allowance for Steel ASTM A106 A = .08
      v. Coolant density 58.656 lb/ft^3
5. Procedure
   a. Calculate design pressure.
   b. Calculate basic wall thickness.
   c. Adjust thickness of wall to account for corrosion.
6. Calculation

(*Note: T1 shown as example, see summary table for T2 and T3 for tank wall thickness sizing)*

a. Design Pressure

$$p = \gamma h = 62.4\frac{\text{lb}}{\text{ft}^2} * .94 * \frac{114.875\text{in}}{12} = 561.5\frac{\text{lb}}{\text{ft}^2} = 3.9\ psi$$

b. Basic wall thickness

$$t = \frac{pD}{2(SE + pY)} = \frac{\left(3.9\frac{\text{lb}}{\text{in}^2}\right)(114.875)}{2\left(\frac{20{,}000\text{lbf}}{\text{in}^2} + (69638.4)(.4)\right)} = .004\text{ in}$$

c. Corrosion allowance

$$t = 1.1439\,(t + A) = 1.143(.004in + .08in) = \ .096\ in$$

7. Summary
   a. Table 1

Tank	Location	Design pressure (PSI)	Tank height	Capacity (US Gal)	Required wall thickness (in)	Sheet metal Gauge req'd
T1	Exterior, Near Train Tracks	3.9	9’-6 7/8”	15000	0.096	12
T2	Interior, in shop area	4.8	11’-0”	1000	0.11	11
T3	Exterior near building front	3.9	9’-6 7/8”	8000	0.096	12

Table 3.6.1.3.1

   b. The tank should be constructed with Steel ASTM A1011.

3.6.1.4. Future Drain Connection

1) Purpose
   a) To allow for future additions to the functionality of the tank.
2) Drawings and diagrams

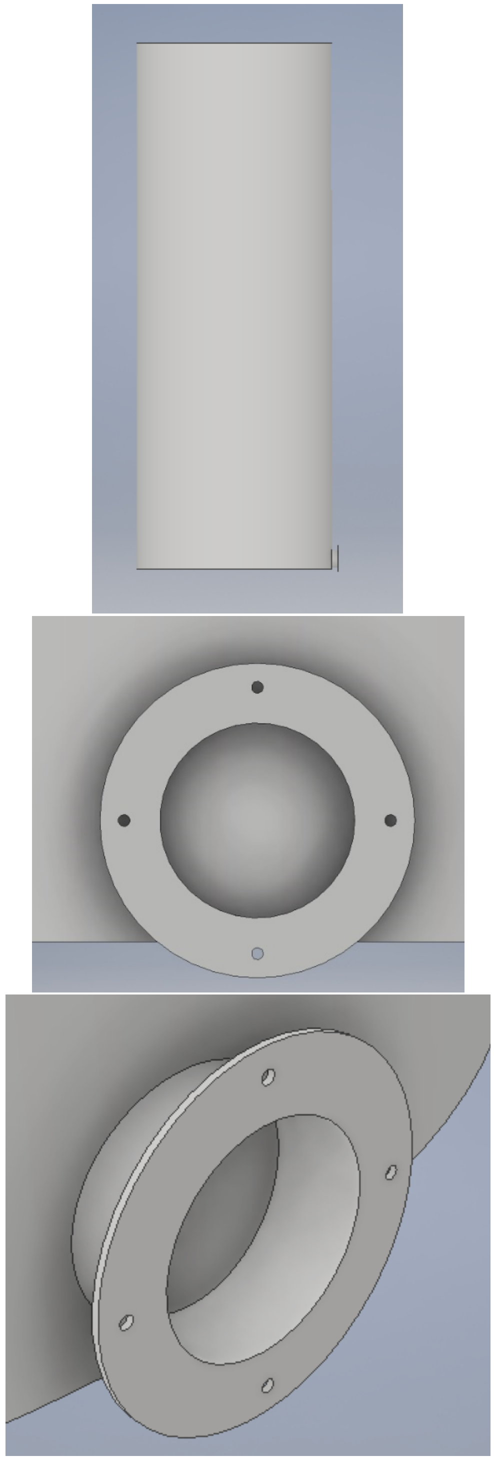


Figure 3.6.1.4

3) Design Considerations
   a) The flange should be made of commercially available material.

b) The flange should use a standard bolt pattern to improve modularity.
c) The flange may at some point be required to bear the weight of some equipment
d) 4in NPS sch. 40 sizing will be used for ID and OD

4) Data
   a) Tank size

$$D = 4'$$

$$H = 11'$$

$$V = 1038\, US\ Gal = 138.28\, ft^3$$

   b) Orifice size

4" NPS sch. 40 sizing standards used

$$I.D. = 0.3355'$$

$$A = 0.08840 ft^2$$

   c) Material properties
      i) Grade 5 steel fasteners

$$Yield\ strength\ (tension) = 92{,}000 psi$$

      ii) Grade 5 steel bolts and mild steel block off plate and flange

$$Yielding\ shear\ strength = 55{,}200 psi$$

      iii) Safety factor

$$F_s = 2$$

5) Calculation
   a) Bolt size calculations

$$P = \frac{58.656 lb}{ft^3} * 10.8\bar{3} ft$$

$$P = \frac{635.44 lb}{ft^3} = 4.413 psig$$

$$F = \frac{635.44 lb}{ft^3} * 0.08840 ft^2$$

$$F = 56.172 lbf$$

Flange will be 4 bolt, therefore…

$$F_{bolt} = F/4$$

$$F_{bolt} = 14.043 lbf$$

Failure mode in this case is yielding as this would cause leakage. A safety factor of 2 will be used to prevent accidental damage. Grade 5 steel fasteners will be used

$$\epsilon_{yield} = 92{,}000psi$$

$$A_{min} = \frac{14.043lbf}{92{,}000psi}$$

$$A_{min} = .0001526ft$$

$$A_{SF} = .000305ft = .00366in$$

$$D_{SF} = \sqrt{\frac{.00366in}{\pi}}$$

$$D_{SF} = .03414in$$

There are no commercially available bolts of .03414in diameter. Because of this and the industrial application, we will simple use 4, 1/4in - 20 bolts. These will provide a safety factor of almost 20x what is required and their cost increase is negligible compared to smaller fasteners.

b) Flange thickness calculations

$$SE = 0.6 * 92{,}000psi$$

$$SE = 55{,}200psi$$

$$T_{min} = D * \sqrt{\frac{3 * 4.313psi}{16 * 55{,}200}}$$

$$T_{min} = 0.0156in$$

We will apply a safety factor of 2

$$T_{SF} = .0312in$$

While this thickness will technically hold, it will dent or bend rather easily if impacted by other equipment, likely causing a leak. For this reason, a far thicker material should be used. 1/4in mild steel plate will resist any unintentional damage the flange may suffer and is still sufficiently inexpensive to be an easily justifiable addition to the system. In addition, if equipment in the future are to use this flange as a mounting point, the flange itself must be sufficiently strong to support that equipment further justifying the use of 1/4 in plate as opposed to .0312in sheet.

6) Summary
  a) Bolt specifications
    i) Minimum recommended size
       4 bolts, ¼”-20 size
  b) Flange specifications
    i) 1/4” plate thickness for both flange and block off plate

3.6.1.5. Wind Load and Weight

1) Purpose
   i) To indicate tank weights and wind loads where applicable.
2) Diagrams

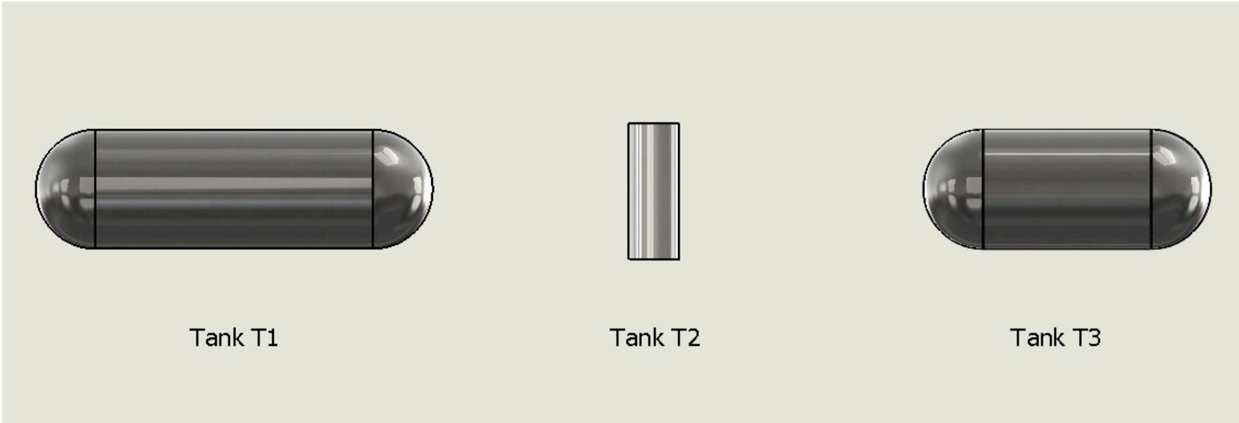


Figure 3.6.1.5.

3) Design Considerations
   i) The maximum wind speed gust recorded in the area Dayton, Ohio is 48 mph. We will add a margin of 20% to it and use 57.6mph.
   ii) The only tank susceptible to wind loading is tank 3, since tank 1 is underground and tank 2 is located in the shop away from the environment.
4) Data
   i) V=57.6mph
   ii) $KV_{air\ at\ -20F}$ =1.17e-4
   iii) Tank 1 vertical diameter is 114 7/8 inches (or 9.57ft) x 277.6 inches wide(or 23.13ft)
   iv) Cylindrical section of tank is 13.56ft
   v) P=2.8 x 10^-3 slug/ft^3
   vi) C_d=1.13(cylinder line)
5) Procedure
   i) Calculate sail area

$$A_{total} = sphere\ area\ projected\ area + cylindrical\ projected\ area$$

$$A_{total} = \frac{\pi}{4}(9.57ft)^2 + 9.57ft * 13.56ft = 201.7\text{ft\^{}2}$$

   ii) Convert to standard velocity units

$$v = 57.6mph\frac{5280ft}{1mile} * \frac{1\ hr}{3600\ sec} = 84.48ft/sec$$

   iii) Calculate wind load
      (a) Find Nr first

$$Nr = \frac{vD}{1.17e^{-4}} = \frac{84.48ft/\sec\,(9.57\ ft)}{1.17e^{-4}} = 6910030$$

      (b) Wind load

$$C_D\left(\frac{Pv^2}{2}\right)A = 1.13\left(\frac{2.8 * 10^{-3} * 84.48^2}{2}\right)201.7ft^2 = 2277.3lb$$

iv) Find Weight of tanks with fluid

$$Tank\ 1 = 15000gal(.134) * (.94 * 32.2) = 60{,}839lb$$

$$Tank\ 2 = 1000gal(.134) * (.94 * 32.2) = 4{,}056lb$$

$$Tank\ 1 = 8000gal(.134) * (.94 * 32.2) = 32{,}447lb$$

6) Summary

a) Tank Weight Data

Tank No.	Wind load if applicable	Weight of tank(dry)	Weight of fluid in tank	Weight of tank with fluid
1	NA	3753 lb	60,000 lb	63,753 lb
2	NA	652 lb	4,056 lb	4,708 lb
3	2,277 lbf	2713 lb	32,447 lb	35160 lb

Table 3.6.1.5.1

3.6.1.6. *Open Channel for Drainage*

1) Purpose
   a) In the future, should tank 3 fail for any reason, it should be able to drain without the presence of a tanker. For this reason, an open channel system should be used to carry the coolant away from the plant.
2) Design Considerations
   a) The maximum flow rate of the channel should be equal to or greater than the maximum flow rate of the drain on the tank.
   b) The open channel will be used very occasionally
   c) Factory equipment may need to cross over the channel and provisions for this should be considered.
      i) To do this without the need to build any bridges or walkways a very shallow aspect ratio will be used if possible.
   d) The channel will be constructed of unfinished concrete for ease of installation and durability.
   e) A drain pad underneath the tank will also be included in the design to eliminate the possibility of soil erosion around the base of the tank, however, its size and slope may be altered by the customer if a larger or smaller drain pad is desired so long as the liquid drains onto the pad into the channel and not around the base of the tank.
   f) The channel will be routed along the west side of the building to the rear until it is sufficiently far from the building as to not cause foundation damage.
3) Data

$$Q_{min} = 1.355\ ft^3/sec$$

$$L = 550ft$$

$$S = 0.5\%$$

$$z = 5$$

4) Calculations
   a) A triangle cross section channel will be used due to its ease of manufacture and the fact that at a low enough aspect ratio, it can be easily driven over by most vehicles
   b) This solution is gained by iterating until the desired solution is achieved. Below is the table of iterations and properties of the selected parameters.

R	V	y	A	Q max	z	y	T	yh	Nf
0.5	3.904233	0.489898	1.2	4.685079	5	0.489898	4.898979	0.244949	1.390176
0.25	2.459512	0.244949	0.3	0.737854	5	0.244949	2.44949	0.122474	1.238506
0.375	3.222873	0.367423	0.675	2.175439	5	0.367423	3.674235	0.183712	1.325094
0.35	3.077994	0.342929	0.588	1.80986	5	0.342929	3.429286	0.171464	1.309945
0.34	3.019082	0.333131	0.55488	1.675228	5	0.333131	3.331306	0.166565	1.303631
0.33	2.959591	0.323333	0.52272	1.547037	5	0.323333	3.233326	0.161666	1.297161
0.32	2.899495	0.313535	0.49152	1.42516	5	0.313535	3.135347	0.156767	1.290526
0.31	2.83877	0.303737	0.46128	1.309468	5	0.303737	3.037367	0.151868	1.283715

Table 3.6.1.6.1

c) You may notice that Froude's Number is above 1 and flow is therefore somewhat supercritical. Normally this would be undesirable, however, due to the occasional nature of its intended use and the requirement for a shallow channel that can be driven over, this is not unacceptable.

5) Summary
   a) The channel shall be a triangle cross section and have the following dimensions
      i) $Slope = 0.5\%$
      ii) $Depth\ =\ 0.314ft$
      iii) $Width = 3.135ft$
   b) The channel shall be made of unfinished concrete.

3.6.2. Flow Rate

1) T1 fill time
   a) Design Considerations
      i) Because the tank will be gravity fed by the train, the height of the fluid will change. To correct for this, one half the height of the tank is used to get Z. This gives average flow rate and will give a more accurate representation of the time it takes to drain this tank.
      ii) To reduce the need for extra manpower during the fill of tank 1, and to reduce the amount of time that the railroad is blocked, a large flow rate is desired.

$$t_{target} = 37.5min$$

$$Q_{target} = 400gpm$$

      iii) To fix the flow rate we must find the pipe size that can give us this flow rate or close to it
   b) Figures
      i) $\Delta z_{avg} = 10.75ft$
      ii) $L = 43ft$
      iii) $K_e = 20f_t$
      iv) $K_v = 0.05ft$
   c) Calculations

Using LHS=RHS the ideal diameter was found.

D/Ɛ	D	A	V	Nr	f	ft	Ke	Kv	LHS	RHS	Diff
2000	0.3	0.070686	12.59092	133237.3	0.019725	0.0165	0.33	0.05	4.366959	3.53718	1.234588
1666.667	0.25	0.049087	18.13093	159884.8	0.019825	0.01675	0.335	0.05	2.105979	4.129967	0.509926
1833.333	0.275	0.059396	14.98424	145349.8	0.019755	0.017	0.34	0.05	3.083364	3.818901	0.807396
1933.333	0.29	0.066052	13.47424	137831.7	0.019732	0.0175	0.35	0.05	3.813169	3.675827	1.037364
1900	0.285	0.063794	13.95116	140249.8	0.019738	0.0175	0.35	0.05	3.556915	3.728054	0.954094
1916.667	0.2875	0.064918	13.70959	139030.2	0.019735	0.0175	0.35	0.05	3.683371	3.701687	0.995052

Table 3.6.2.1

Now the next largest sch. 40 pipe is selected and actual Q is found. 3.5 in sch. 40 pipe.

D	D/Ɛ	A	f	ft	Ke	Kv	V	Q	Nr	f	Diff
0.2957	1971.333	0.06868	0.019375	0.0175	0.35	0.05	12.31146	0.845551	128412.6	0.019841	1.024035

Table 3.6.2.2

$$Q = \frac{0.845550872}{sec} = 379.5gpm$$

$$t = \frac{15000gal}{379.5gpm}$$

$$t = 39.5min$$

2) T2 fill time
   a) Design Considerations
      i) This system will use a fixed flow rate at 50gpm
      ii) This system will be pumped

iii) Tank 2 has a capacity of 1000 gallons

b) Calculations

$$t = \frac{1000gal}{50gpm}$$

$$t = 20\ min$$

3) T3 Empty

a) Design Considerations

i) Because the tank will be gravity fed, the height of the fluid will change. To correct for this, one half the height of the tank is used. This gives average flow rate and will give a more accurate representation of the time it takes to drain this tank.

ii) Tank 3 has a capacity of 8000 gallons

$$t_{target} = 20\ min$$

$$Q_{target} = 400gpm$$

b) Figures

i) $\Delta z_{avg} = 6.766ft$

ii) $L = 13ft$

c) Calculations

i) Solve this system by iterating in Excel using the LHS=RHS method

D/Ɛ	D	A	V	Nr	f	ft	Ke	Kv	LHS	RHS	Diff
2000	0.3	0.070686	12.59092	133237.3	0.019725	0.0165	0.33	0.05	2.748544	1.564729	1.756562
1666.667	0.25	0.049087	18.13093	159884.8	0.019825	0.01675	0.335	0.05	1.325494	1.75092	0.757027
1833.333	0.275	0.059396	14.98424	145349.8	0.019755	0.017	0.34	0.05	1.940655	1.663854	1.166362
1800	0.27	0.057256	15.54435	148041.4	0.019765	0.0175	0.35	0.05	1.803319	1.701656	1.059744
1766.667	0.265	0.055155	16.13646	150834.7	0.019777	0.0175	0.35	0.05	1.673405	1.720213	0.97279
1786.667	0.268	0.05641	15.77722	149146.2	0.01977	0.0175	0.35	0.05	1.750479	1.708985	1.024279

Table 3.6.1.3

ii) The ideal ID is .268ft, the next larger sch.40 pipe is 3.5in sch.40

iii) Now solve for actual flow rate

D	D/Ɛ	A	f	ft	Ke	Kv	V	Q	Nr	f	Diff
0.2957	1971.333	0.06868	0.019375	0.0175	0.35	0.05	12.94114	0.888798	134980.5	0.01973	1.018341

Table 3.6.1.4

$$Q_{avg} = \frac{0.88798ft^3}{sec} = 398.6gpm$$

$$t = \frac{8000gal}{398.6gpm}$$

$$t = 20.1min$$

3.6.3. Pipe Sizing

3.6.3.1. Piping Layout

a) Below is a line diagram of the system, neither direction or scale are preserved.

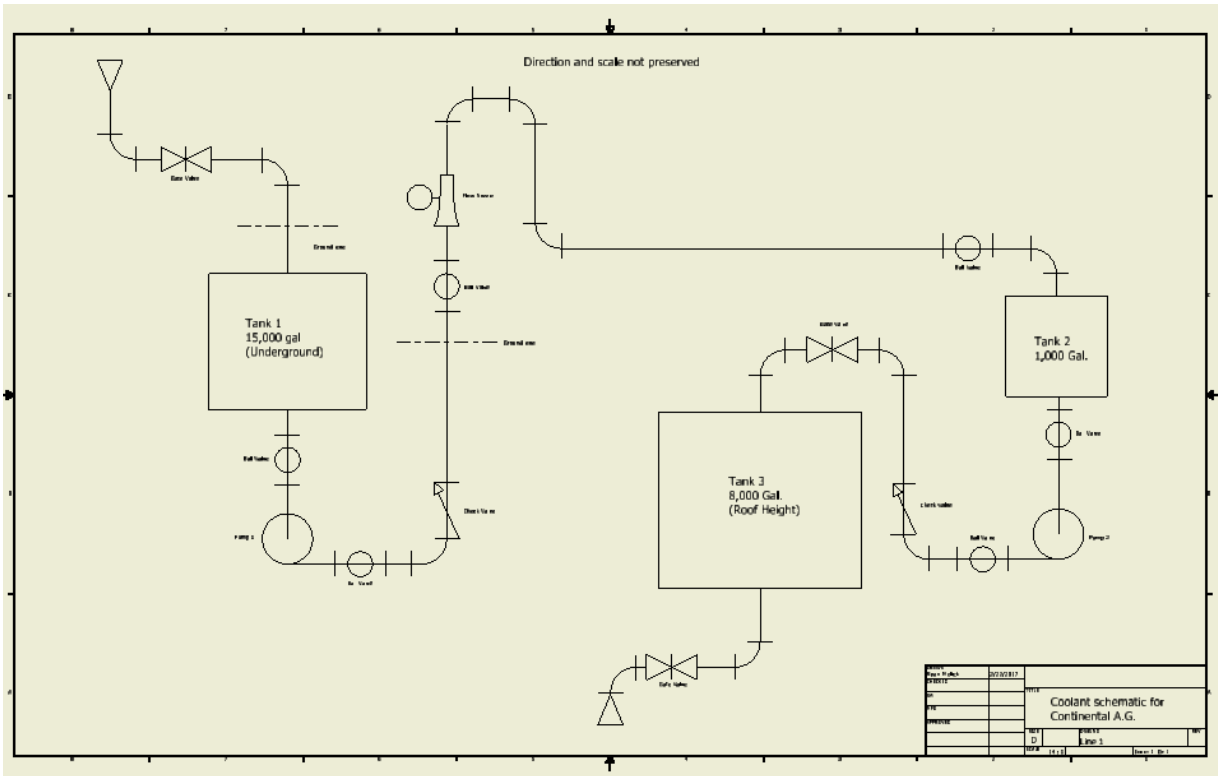


Figure 3.6.3.1

3.6.3.2. Preliminary Pipe Diameter and Lengths

i) The diameter of both the pipes from train to tank and tank to truck will be 4 inch NPS schedule 40 pipe. The transfer pipes from clean tank to working tank, and working tank to dirty tank will be 1.5 inch NPS schedule 40 pipe.

ii) The length of straight run of pipe between the train and tank is 42.5 feet. The length of straight run between the clean tank and working tank is 589 feet. The length of pipe between the working tank and dirty tank is 539 feet. The length of pipe between the dirty coolant tank and the recycling truck is 42.5 feet.

3.6.3.3. Pipe Thickness

b) Purpose

   i) To specify the pipe wall thickness for our system

c) Drawings and Diagrams.

Pipe OD=4.0''

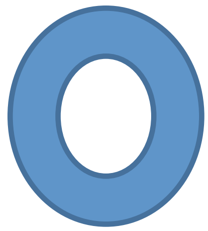


Figure 3.6.3.3

d) Design Considerations

   i) Pipes at end of pumps

   ii) For the clean coolant tank and for reservoir tank

e) Data and Variables

   i) Pipe size OD =4.0'

   ii) Head loss pump 1 (max)=92.24ft

   iii) Head loss pump 2 = 84.46ft

   iv) Material property

      (1) Allowable stress for Steel ASTM A106 s= 20000lbf/in^2

      (2) Longitudinal joint quality factor E = 1

      (3) Correction factor y = .4

      (4) Corrosion allowance for Steel ASTM A106 A = .08

f) Procedure -

   i) Find pressure max and then find pipe thickness using equation in chapter 11 (11-9)

   ii) Adjust thickness of wall to account for corrosion

g) Calculation

$$p=\Upsilon[z1-z2-\frac{v^2}{2g}-h_l]$$

$$p=62.4lb/ft^2[\frac{(7.9ft/sec)^2}{2(32.3ft/sec^2)}-92.24ft]$$

$$p=5695.3 \ \ lb/ft^2 \ \ or$$

$$p=39.54 \ \ psi$$

h) Basic wall thickness

$$t=\frac{pD}{2(SE+pY)}=\frac{\left(39.54\frac{lb}{in^2}\right)(4in)}{2\left(\frac{20{,}000lbf}{in^2}+(39.54lb/in\hat{}2)(.4)\right)}=.004\ in$$

i) Summary

i) The pipe wall thickness for max operating pressure is .004in

3.6.3.4. Fittings

ii) For placement of fittings see line drawing above, [SECTION].

(1) The number and type of fittings is as follows.

(a) 4 inch NPS Sch.40 long radius 90-degree elbow – 4

(b) 1.5 inch NPS Sch.40 long radius 90-degree elbow - 9

(c) 4 inch NPS Sch.40 gate valve – 2

(d) 1.5 inch NPS Sch.40 gate valve – 1

(e) 1.5 inch NPS Sch.40 ball valve – 5

3.6.3.5. Water Hammer

j) Purpose
   (1) To check system piping for water hammer problems.

k) Design Considerations
   (1) The maximum velocity of the region of piping from the train to tank 1's is 13.93ft/s
   (2) The maximum velocity of the remaining regions (from tank 1 to tank 3) of piping is 17.93ft/s
   (3) The velocity for train to tank 1 is not critical since it is lower and the pipe has more circumference to absorb the stresses.

l) Data
   (1) Pipe Sizing
      (i) From Tank 1 to 3 is 1.5 inch schedule 40
      (ii) From Train to Tank 1 is 4 inch schedule 40
   (2) Symbols
      (i) E'=modulus of elasticity of pipe and liquid
      (ii) d= id of pipe
      (iii) e=Poisson's ratio
      (iv) Ep=modulus of elasticity for pipe
      (v) Ew= modulus of elasticity of liquid
      (vi) t= wall thickness of pipe

m) Procedure
   (1) Calculate maximum water hammer pressure.
      (i) (Note: calculations only show for critical case see table for values for the 4 inch sch 40 pipe)
   (2) Find combined modulus of elasticity of pipe and liquid:

$$E' = \frac{1}{\left(\frac{1}{E_w}\right)\left(\frac{d}{4tE_p}\right)(5-4e)}$$

$$E' = \frac{1}{\left(\frac{1}{3000000}\right)\left(\frac{1.61}{4*.145*10900000}\right)(5-4*.3)} = 768301psi$$

   (3) Find change in pressure:

$$\Delta p = \frac{v_{max}\sqrt{\frac{\gamma}{32.2}*E'}}{12} = \frac{17.93ft/s\sqrt{\frac{62.4*.095}{32.2}*768301}}{12} = 1777.4\ psi$$

n) Summary

o) Table Water Hammer Summary

Pipe Size(NPS)	Max Velocity ft/s of fluid	Resultant Water Hammer(PSI)
1.5 sch. 40	17.93	1777
4 sch. 40	13.53	1136

Table 3.6.3.5

p) All these values for water hammer are in the safe range of stress, no additional arrestor will be required in the system.

3.6.4. Pipeline Support Info

1) Purpose
   a) Determine type of supports and determine the force acting on each support for a particular pipe system.
2) Drawings and diagrams
   a) Pipe system- Straight pipe: L=589ft (Between Clean Storage Tank (T1)-Working coolant tank (T2). Check diagram for reference.

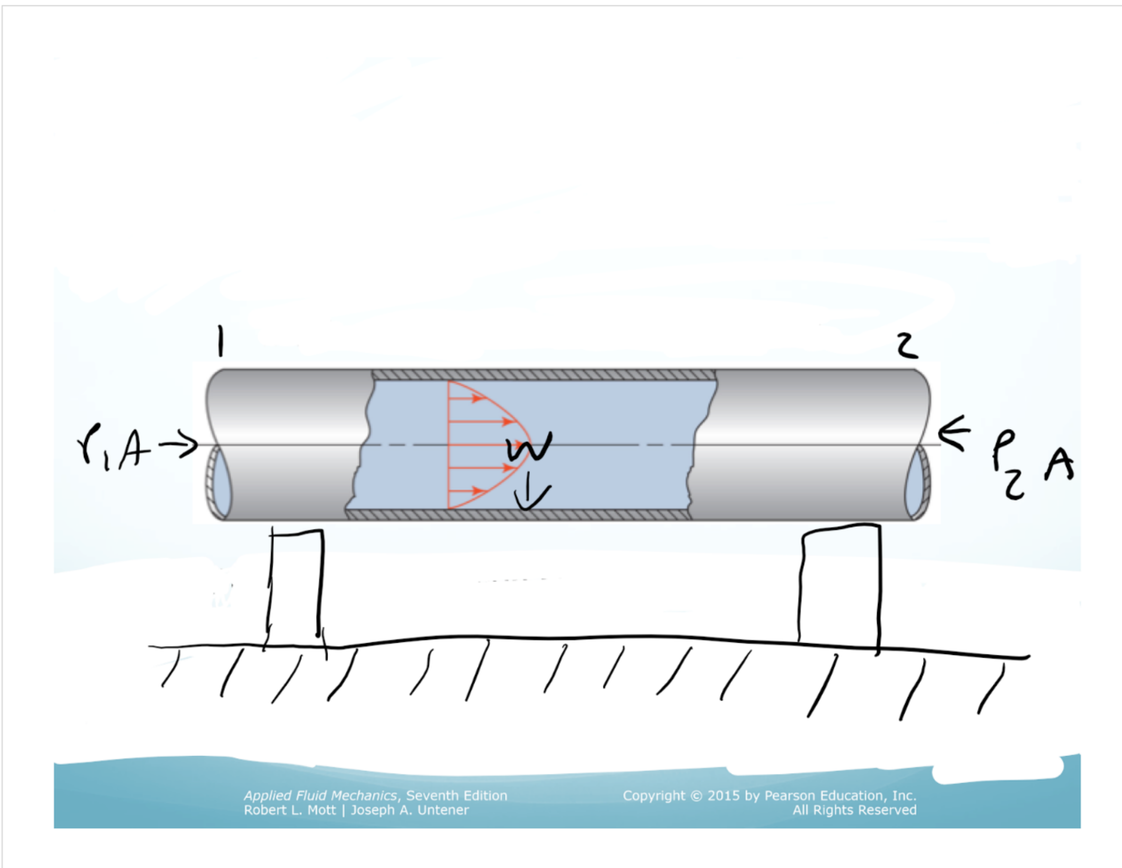


Figure 3.6.4

3) Design Considerations
   a) Support system to be designed for the straight pipe section from the clean storage tank (T1) to working coolant tank (T2).
   b) Horizontal Support
   c) Beam Deflection
   d) Because we are using a Horizontal Support we will only be looking at the forces acting on the support system in the y-direction
   e) Civil Engineers will help design the support system

4) Data and Variables

$$A = .01414\ ft^2$$

$$V = 7.9\ ft/s$$

$$Weight\ of\ 1\frac{1}{2}\ in\ SCH\ 40\ pipe = W_{pipe} = 2.72 lb/ft$$

$$Specific\ Gravity\ Of\ coolant = .94$$

5) Procedure:
   a) Use Force equations to solve for forces acting on each support.
   b) $Fx = pQ(V_{2x} - V_{1x})$
   c) $Fy = pQ(V_{2y} - V_{1y})$
   d) Forces in a Straight pipe in
      i) X-direction: $R_x = (P_2 - P_1)$A
   e) Because we are using a Horizontal Support we will only be looking at the forces acting on the support system in the y-direction
   f) Y-Direction: $R_y = W = W_{pipe} + sg_{coolant}$
6) Calculations :

$$R_y = W = W_{pipe} + W_{coolant} = 2.72\frac{lb}{ft} + .94$$

$$R_y = 3.66\frac{lb}{ft}$$

7) Summary :

   a) Using Horizontal Supports

$$R_y = 3.66\frac{lb}{ft}$$

3.6.5. Energy Losses

1) Pipe 2
   a) Purpose
      i) To determine head loss in the coolant system in region from pump to 1000 gallon reservoir T2.
   b) Drawings and Diagrams

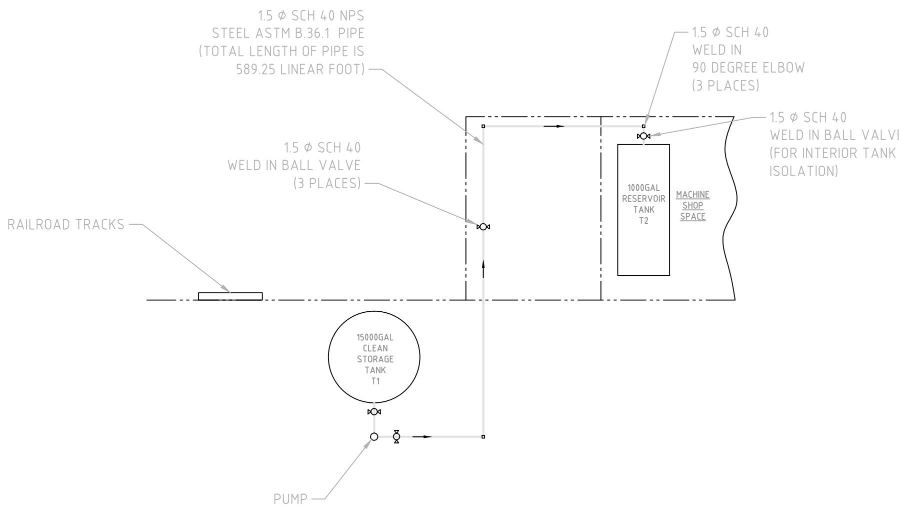


Figure 3.6.5.1

   c) Design Considerations
      i) The 1000 gallon tank(T2) will be located indoors
      ii) The 15000 gallon Clean storage tank(T1) is located in the ground.
      iii) Approximately 589 linear feet of 1 ½ sch 40 NPS is require to plum the coolant from the exterior 15000(T1) Clean storage tank to the interior 1000 gallon Reservoir(T2)
      iv) The coolant viscosity is 1.5 time the viscosity of water.
   d) Data and Variables
      i) K values for fittings:
         (1) Ball Valve = .06
         (2) Long 90 degree elbow = .021
      ii) Material property
         (1) Pipe and Fittings are Steel ASTM A106
   e) Procedure
      i) Identify material quantity's and lengths (see table 2)
      ii) Identify total head loss and tabulate each section of the pipe run
   f) Calculations

$$N_R = \frac{\upsilon D}{\text{v}} = \frac{\left(\frac{7.9ft}{s}\right)(.1342ft)}{1.5(.926\ x\ 10^{-5})} \qquad N_R = 76332$$

$$Realative\ Roughness = \frac{D}{\varepsilon} = \frac{.1342}{1.5\ x\ 10^{-4}} = 895 \qquad \text{f=.023}$$

$$ft = .021$$

i) Head Losses

$$h_{L_{Pipe}} = f\ x\ \frac{L}{D}\ x\ \frac{v^2}{2g} = .023x\ \frac{589.3}{.1342}\ x\ \frac{7.9^2}{2(32.2)} = 97.88\ ft$$

$$h_{L_{Long\ Elbow}} = (5)20ft\left(\frac{v^2}{2g}\right) = 100(.021)\left(\frac{7.9^2}{64.4}\right) = 2.04\ ft$$

$$h_{L_{Ball\ Valve}} = (4).06ft\left(\frac{v^2}{2g}\right) = .24(.021)\left(\frac{7.9^2}{64.4}\right) = .005\ ft$$

Head Loss Per System Component Comparison (T1 to T2)			
Component	Head loss per unit	Quantity required	Total head loss (LF)
Pipe	3.57	1	97.88
Long Elbow	.344	5	2.04
Ball Valves	0.001	4	.005
		Total Heat loss	99.93

Table 3.6.5.1

g) Summary
   i) The total head loss from clean storage pump to reservoir (T1 to T2) is 99.93 Linear Feet.

2) Pipe 3
   a) Purpose
      i) To determine head loss in the coolant system in region from pump in the machine shop to the 1000-gallon dirty storage tank(T3) outside.
      ii) Drawings and Diagrams

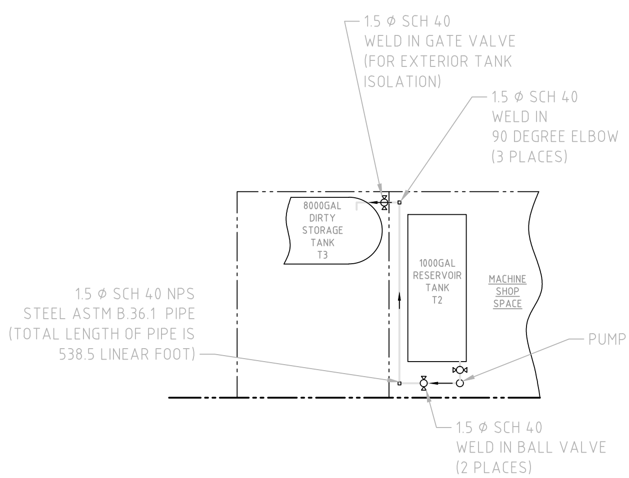


Figure 3.6.5.2

   b) Design Considerations
      i) The 1000gallon tank(T2) will be located indoors
      ii) The 8000gallon(T3) dirty storage tank is located on the exterior of the build near the driveway.

iii) Approximately 539 linear feet of 1 ½ sch 40 NPS is require to plum the coolant from the interior 1000gallon Reservoir exterior to the 8000 dirty storage tank(T3).
iv) The coolant viscosity is 1.5 time the viscosity of water.
v) K values for fittings:
    (1) Ball Valve = .06
    (2) Gate Valve = 8
    (3) Long 90 degree elbow = .021
vi) Material property
    (1) Pipe and Fittings are Steel ASTM A106

c) Procedure
    i) Identify material quantity's and lengths (see table 2)
    ii) Identify total head loss and tabulate each section of the pipe run

d) Calculations

$$N_R = \frac{\upsilon D}{\text{v}} = \frac{\left(\frac{7.9ft}{s}\right)(.1342ft)}{1.5(.926\ x\ 10^{-5})}$$

$$N_R = 76332$$

$$Realative\ Roughness = \frac{D}{\mathcal{E}} = \frac{.1342}{1.5\ x\ 10^{-4}} = 895$$

$$f = .023$$

$$ft = .021$$

i) Head Losses

$$h_{L_{Pipe}} = f\ x\ \frac{L}{D}\ x\ \frac{v^2}{2g} = .023\ x\ \frac{538.5}{.1342}\ x\ \frac{7.9^2}{2(32.2)} = 89.44ft$$

$$h_{L_{Long\ Elbow}} = (3)20ft\left(\frac{v^2}{2g}\right) = 60(.021)\left(\frac{7.9^2}{64.4}\right) = 1.22\ ft$$

$$h_{L_{Ball\ Valve}} = (2).06ft\left(\frac{v^2}{2g}\right) = .12(.021)\left(\frac{7.9^2}{64.4}\right) = .002\ ft$$

$$h_{L_{Gate\ Valve}} = (1)8ft\left(\frac{v^2}{2g}\right) = 8(.021)\left(\frac{7.9^2}{64.4}\right) = .163\ ft$$

Head Loss Per System Component Comparison(T2 to T3)			
Component	Head loss per unit	Quantity required	Total head loss (LF)
Pipe	89.44	1	89.44
Long Elbow	.41	3	1.22
Ball Valve	0.001	2	0.002
Gate Valve	.163	1	.163
		Total Heat loss	95.34

Table 3.6.5.2

e) Summary
   i) The total head loss from reservoir pump to the dirty storage tank (T3) is 95.34 Linear Feet.
f) Summary of Head Losses for Systems

Region of System	Head loss(feet)
T1 to T2	99.93
T2 to T3	95.34

Table 3.6.5.3

3.6.6. Pump Selection

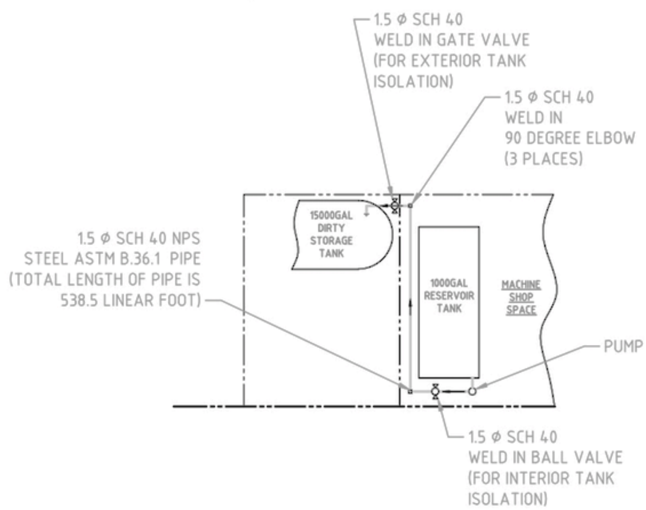
3.6.6.1. Pump Requirements

a) Pipe 2

i) Purpose

(1) To determine head loss in the coolant system in region from pump in the machine shop to the 1000-gallon dirty storage tank outside.

ii) Drawings and Diagrams.



iii)

Figure 3.6.6.1

iv) Design Considerations- pumps located at end of tanks

(1) The 1000 gallon tank will be located indoors

(2) The 15000 gallon Dirty storage tank is located on the exterior of the build near the driveway.

(3) Approximately 539 linear feet of 1 ½ sch 40 NPS is require to plum the coolant from the interior 1000 gallon Reservoir exterior to the 15000 Clean storage tank.

(4) The coolant viscosity is 1.5 time the viscosity of water.

(5) K values for fittings:

(a) Ball Valve = .06

(b) Gate Valve = 8

(c) Long 90 degree elbow = .021

(6) Material properties

(a) Pipe and Fittings are Steel ASTM A106

v) Data and Variables

(1) V=7.9ft/sec

(2) D=. 3142ft

(3) A=.01414 ft^2

(4) hl at 15,000 gallon clean storage tank(T1-T2) =99.93ft

(5) hl at 1000 gallon reservoir tank (T2-T3)=95.34ft

(a) (Refer to 3.6.5 Energy Losses for hl)

vi) Procedure

(1) Solve for flow rate for each pump

(2) Solve for pump head in each pump

vii) Calculations

(1) Pump 1 (15,000 gallon clean storage tank)

$$Q = VA = \left(\frac{7.9ft}{\sec}\right)(.01414ft^2) = .111706ft^3(\frac{7.5gal}{\sec})(60\min)$$

$$Q = 50.27\ gallon/min$$

$$h_a = h_l + (z1 - z2)(\frac{v^2}{2g})$$

$$h_a = 99.93ft + 25ft(\frac{7.9^2ft/sec}{2*32.2\frac{ft}{sec^2}})$$

$$h_a = 124.2ft$$

(2) Pump 2 (1,000 gallon clean storage tank)

$$Q = VA = \left(\frac{7.9ft}{\sec}\right)(.01414ft^2) = .111706ft^3(\frac{7.5gal}{\sec})(60\min)$$

$$Q = 50.27\ gallon/min$$

$$h_a = h_l + (z1 - z2)(\frac{v^2}{2g})$$

$$h_a = 95.34ft + 39ft(\frac{7.9^2ft/sec}{2*32.2\frac{ft}{sec^2}})$$

$$h_a = 133.1ft$$

viii) Summary

Pump	Flow rate (Q)	Pump head (ha)
1	50.27 gal/min	124.2ft
2	50.27 gal/min	133.1ft

Table 3.6.6.1

3.6.6.2. *Pump Selection*

b) Purpose:

   i) To specify the characteristics of the chosen pumps, point of operation, actual pump size and weight. Include pump curves with system curve, and point of operation. Provide page of pump in the SULZER catalog.

c) Drawings and Designs: Pump Dimensions from SULZER catalog

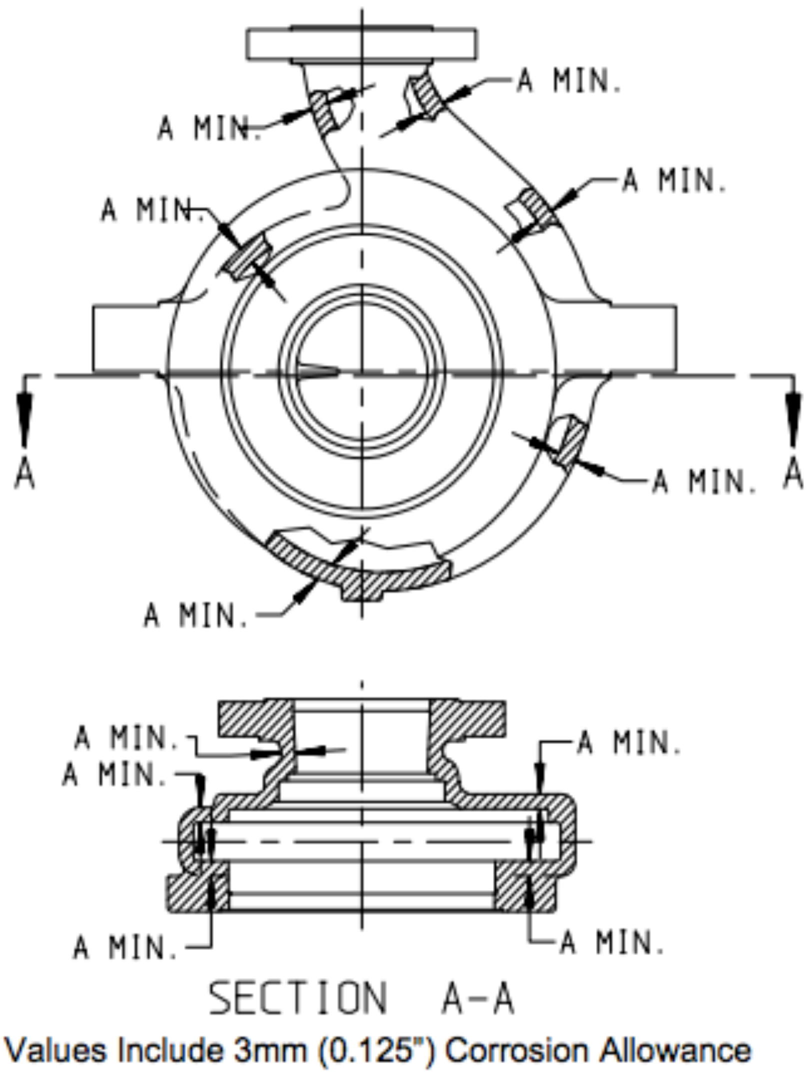


Figure 3.6.6.2

d) Design Considerations:

   i) The technique we used to select the two pumps was a scaling technique suggested by the group leader Ryan Melick, the scaling technique is done by switching the original 3600 rpm speed to our needed 1800rpm speed. We did that by

      (1) $scale = (\frac{rpm_{new}}{rpm_{old}})^2 = (\frac{1800}{3600})^2 = .25$

   ii) Now we multiplied all the units needed by .25 and that will work for our 1800 rpm speed.

iii) When using this scaling technique it is important to remember that we have to scale everything on the information needed on the pump correctly in order for everything to match.
iv) If points do not end up on an impeller size then use affinity laws to din the right impeller size.

e) Data and Variables:
   i) **Pump 1**:
      (1) 1.5 x 4 x 14B-1 OHH SULZER pump.
      (2) Speed= 1800 RPM and 60Hz
      (3) Flow Capacities (Q) = 50.27gpm
      (4) Head Requirements (h_a)= 124.2ft
   ii) **Pump 2**:
      (1) 1.5 X 3 X 11.5-1 OHH SULZER pump.
      (2) Speed = 1800RPM and 60Hz
      (3) Flow Capacities (Q) = 50.27gpm
      (4) Head Requirements (h_a)= 133.1ft
f) Procedure and Calculations:
   i) We go to the SULZER Range of Performances- 60Hz and find our rpm we need for the pump. The 3600-rpm speed did not work so we went with the 1800-rpm speed and scaled it. After scaling everything correctly we have to choose an impeller size by using our values for flow and head. Then apply points to get a system curve.
   ii) The operating point is found at the intersection of red and green lines on the drawing and diagrams section. Which is the intersection of the pump curve and system curve.
   iii) To find pump weight and size we referred to the SULZER catalog:
   iv) Weight for pump 1 found in page 175, size in page 191
   v) Weight for pump 2 found in page 172, size in page 191
   vi) For Pump 1:
   vii) When using our values we got for flow (Q= 50.27gpm) and head (h_a= 124.2 ft.) on the pump curve chart it landed on the 11.94 in impeller size. We will now use the 11.94in impeller size
g) Operating Point:
   i) Capacity=Q=50.27 gpm
   ii) Total head= h_a= 124.2ft
   iii) Efficiency $\approx$ 38%
   iv) System Curve= Green

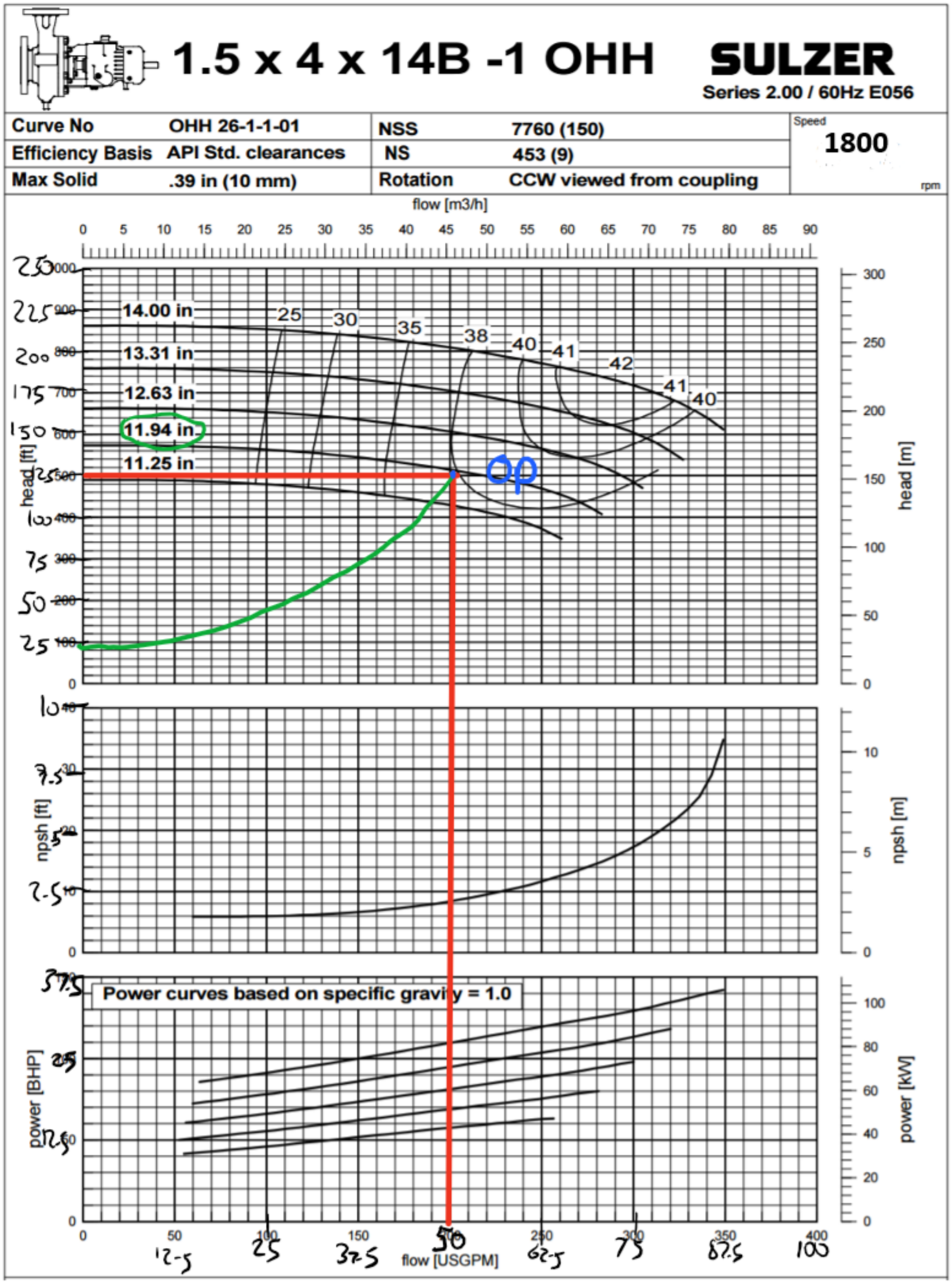


Figure 3.6.6.3

h) For Pump 2:
   i) When using our values we got for flow (Q= 50.27gpm) and head (h_a= 133.1ft.) on the pump curve chart it landed on the 11.50 impeller size. We will now use the 11.50 impeller size.
   ii) Operating point:
   iii) Capacity=Q=50.27 gpm

iv) Total head= h_a= 133.1ft
v) Efficiency $\approx 50\%$
vi) System Curve= Green

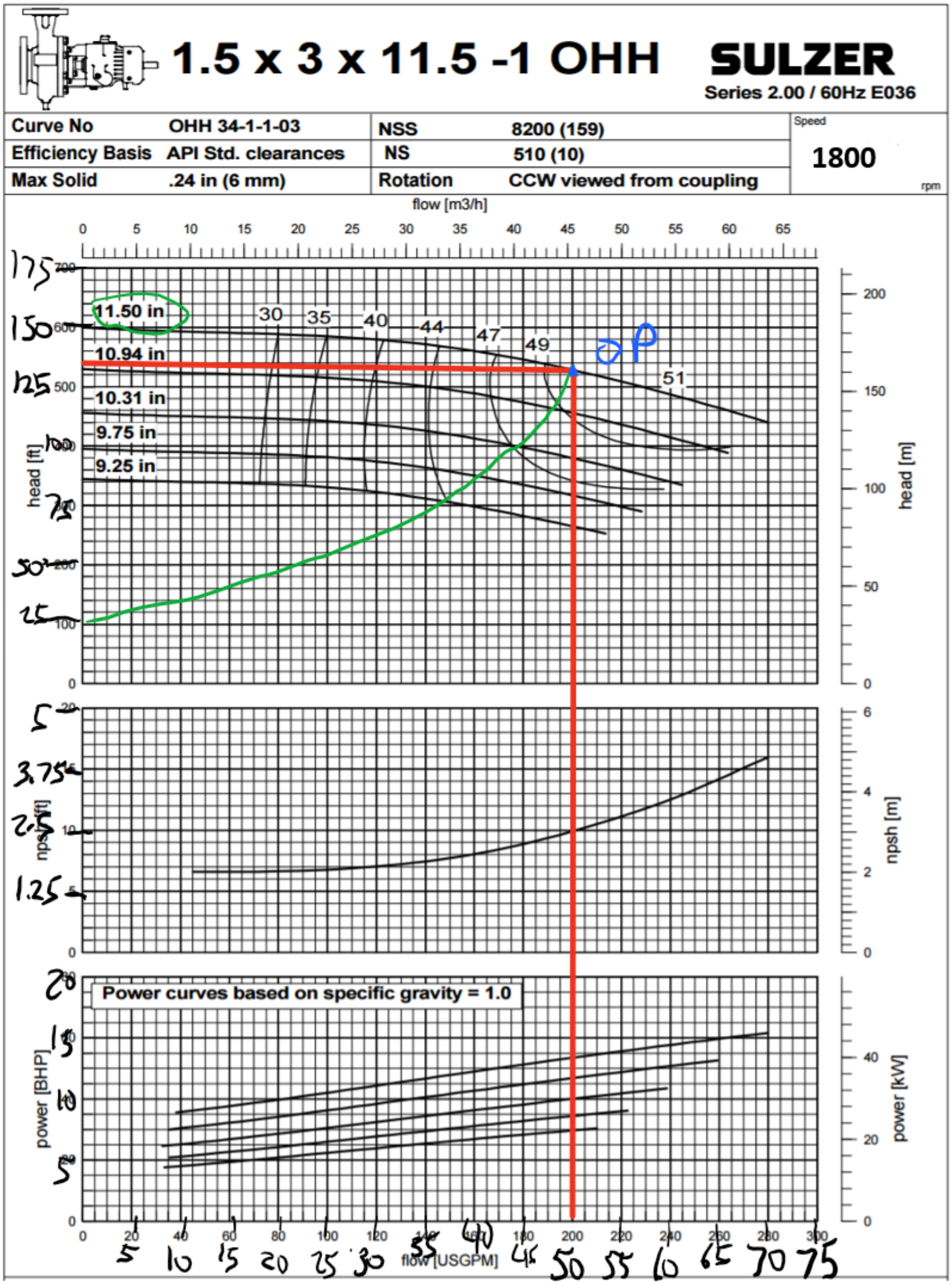


Figure 3.6.6.4

i) Summary:

	Pump 1	**Pump 2**
Type:	1.5 x 4 x 14B-1 OHH SULZER pump. Speed= 1800 RPM and 60Hz	1.5 X 3 X 11.5-1 OHH SULZER pump. Speed = 1800RPM and 60Hz
Point of Operation:	Capacity=Q=50.27 gpm Total head= h_a= 124.2ft Efficiency ≈38%	Capacity=Q=50.27 gpm Total head= h_a= 133.1ft Efficiency ≈50%
Pump Size:	.55 in	.48 in
Pump Weight:	661 lb.	523 lb.

Table 3.6.6.2.1

2) Electrical Motor Specifications
   a) Purpose:
      i) Find the electrical motor requirement needed for our pumps. The electrical engineering colleagues will need this.
   b) Design Considerations:
      i) Power of the electrical motor is about 1.10 times the power required by the pump.
   c) Data and Variables:
      i) Pump 1:
         (1) Head Requirements (h_a)=124.2ft
         (2) Flow Capacities Q = 50.27gpm =.111706 ft$^3/sec$
      ii) Pump 2:
         (1) Head Requirements (h_a)=133.1ft
         (2) Flow Capacities (Q) = 50.27gpm =.111706 ft$^3/sec$
   d) Procedure:
      i) Since the power of the electrical motor is 1.10 times the power required by the pump we will multiply 1.10 and the power required by the pump.
   e) Calculations:
      i) Pump 1:

$$P = h_a\gamma Q = (124.2ft)\left(\frac{62.4lb}{ft^2}\right)\left(\frac{.111706ft^3}{sec}\right)$$

$$P = 865.7\ lb - ft/sec\ (\frac{1.356W}{1lb - ft/sec})\left(\frac{1hp}{745.7W}\right) = 1.57hp * 1.10$$

P= 1.727 hp

         (1) Pump 2:

$$P = h_a\gamma Q = (133.1ft)\left(\frac{62.4lb}{ft^2}\right)\left(\frac{.111706ft^3}{sec}\right)$$

$$P = 927.8\ lb - ft/sec\ (\frac{1.356W}{1lb - ft/sec})\left(\frac{1hp}{745.7W}\right) = 1.69hp\ *\ 1.10$$

$$P = 1.859\ hp$$

   f) Summary:

	Pump 1	Pump 2
Electrical Motor Requirement:	1.727 hp	1.859 hp

Table 3.6.6.3.2

3.6.6.3. Cavitation

h) Purpose
   i) To evaluate the NPHS available at the inlet of the pumps in our system and check that there is adequate pressure for the pumps to operate.

i) Design Considerations
   i) The system contains two pumps.
   ii) Both suction lines assembly are identical to lower cost and to reduce calculation.
   iii) Affinity laws were used to convert a Sulzer pump curves to our application and get exact values.
   iv) The NPSH available in our system must be greater than 110% of the NPSH the pump requires in the worst-case scenario, which is when the tank is completely drained. This is important to ensure the pump performs correctly.
   v) The coolant viscosity is 1.5 time the viscosity of water.

j) Data and Variables
   i) K values for fittings:
   ii) Ball Valve = 8
   iii) Long 90-degree elbow = 30

k) Pump Data

Pump	Part No.	Impeller Size	$NPSH_{110\%}$(ft)	RPM	Q(flowrate)gpm
P1	1.5 x 4 x 14	11.94	1.77	1800	50.27
P2	1.5 x 3 x 11.5	11.5	1.88	1800	50.27

Note: $NPSH_{110\%}$ values were derived from Sulzer pump date using Affinity laws.

Table 3.6.6.4.1

l) Material property
   i) Pipe and Fittings are Steel ASTM B.36.1

m) Procedure
   i) Produce NPSH curve from pump data from Sulzer pump by using affinity laws
   ii) Obtain equation from curve produced and it plug in 50.27gpm the equation as the x value get the NPSH value for our flowrate.
   iii) Check to make sure our system provides adequate NPSH to allow the pump to operate.

n) Calculations

Note: calculation apply to both section line assemblies

$$h_s = 2.919ft \ (distance\ from\ bottom\ of\ tank\ to\ inlet\ of\ pump)$$

$$v = \frac{Q}{A} = \frac{50.27gpm\frac{1}{449}}{.139ft^{\wedge}} = .8055\frac{ft}{s^2}$$

$$N_R = \frac{\upsilon D}{\text{v}} = \frac{\left(\frac{.8055ft}{s}\right)(.4206ft)}{1.5(.926\ x\ 10^{-5})} \qquad N_R = 2.4x10^4$$

$$Realative\ Roughness = \frac{D}{\varepsilon} = \frac{.4206}{1.5\ x\ 10^{-4}} = 2804 \qquad f = .026\ \ ft = .015$$

$$\frac{v^2}{2g} = \frac{.8055^2}{64.4ft/sec} = 0.01ft$$

$$h_f = f\left(\frac{L}{D}\right)0.01ft + 2f_t(30)0.01ft + f_t(8)0.01ft + .01ft$$

$$h_f = .026\left(\frac{2.919}{0.4206}\right)0.01ft + 2(0.015)(30)0.01ft + 0.015(8)0.01ft + .01ft$$

$$h_f = 0.022$$

$$Vapor\ Pressure = 1.5\ Yw@70F = .8393 * 1.5 = 1.26ft$$

$$Pabs = 14.61lbft\text{^}2$$

$$Hsp = \ Pabs/Y = 14.6/(62.4 * .094) = .2489ft$$

$$NPSHa = \ .2489 + 2.919 - 0.022 - 1.26 = 1.88ft\ (meets\ 110\%\ of\ pump\ requirement)$$

o) Summary

i) The system is arranged so that both suction lines are identical. By using 5 inch schedule 40 nominal pipe size from the tank to a reducer (5 inch NPS to a 4 inch NPS) which will be installed at the inlet of the pump we are able to obtain value of 1.88ft NPSH available at the inlet of both pumps. The bottom of each tank shall be located 2.92 ft above the inlet of the pump to eliminate suction head problems. The suction lines should have a valve inline to allow for disconnect of the pumps. Refer to section 20 for material list.

3.6.7. Instrument Selection

1) Design Considerations
   a) The flow meter will be used to measure the flow rate between tanks 1 and 2
   b) The Flow nozzle type was chosen due to its good balance of cost effectiveness and lack of impact on the rest of the system.
   c) The manometer fluid chosen is mercury because of its inability to mix with the coolant and compact manometer scale size
2) Variables
   a) $\beta = 0.5$
   b) $D = 0.1342ft$
   c) $A = 0.01414ft^2$
   d) $Q = 50gpm = \frac{0.1114ft^3}{sec}$
   e) $V = \frac{7.87ft}{sec}$
   f) $\gamma = \frac{58.656lb}{ft^3}$
   g) $N_r = 76{,}332$
3) Calculations

$$d = 0.5 * 0.1342ft$$

$$d = 0.0671ft$$

$$C = 0.9975 - 6.53\sqrt{0.5/76{,}332}$$

$$C = 0.9808$$

$$\Delta P = \frac{(7.87/.9808)^2 * \left(\left(\frac{0.01414}{0.003536}\right)^2 - 1\right) * \gamma}{2 * 32.2}$$

$$\Delta P = \frac{879.112lb}{ft^2} = 6.105psig$$

$$\Delta H = 879.112\frac{lb}{ft^2}/844.9\frac{lb}{ft^3}$$

$$\Delta H = 1.0405ft$$

4) Summary
   a) The flow nozzle inner diameter should be 0.0671ft
   b) The manometer minimum recommended height is 14 inches
   c) The manometer fluid chosen was mercury

3.7. Final Drawings

3.7.1. Plot Plan Drawing

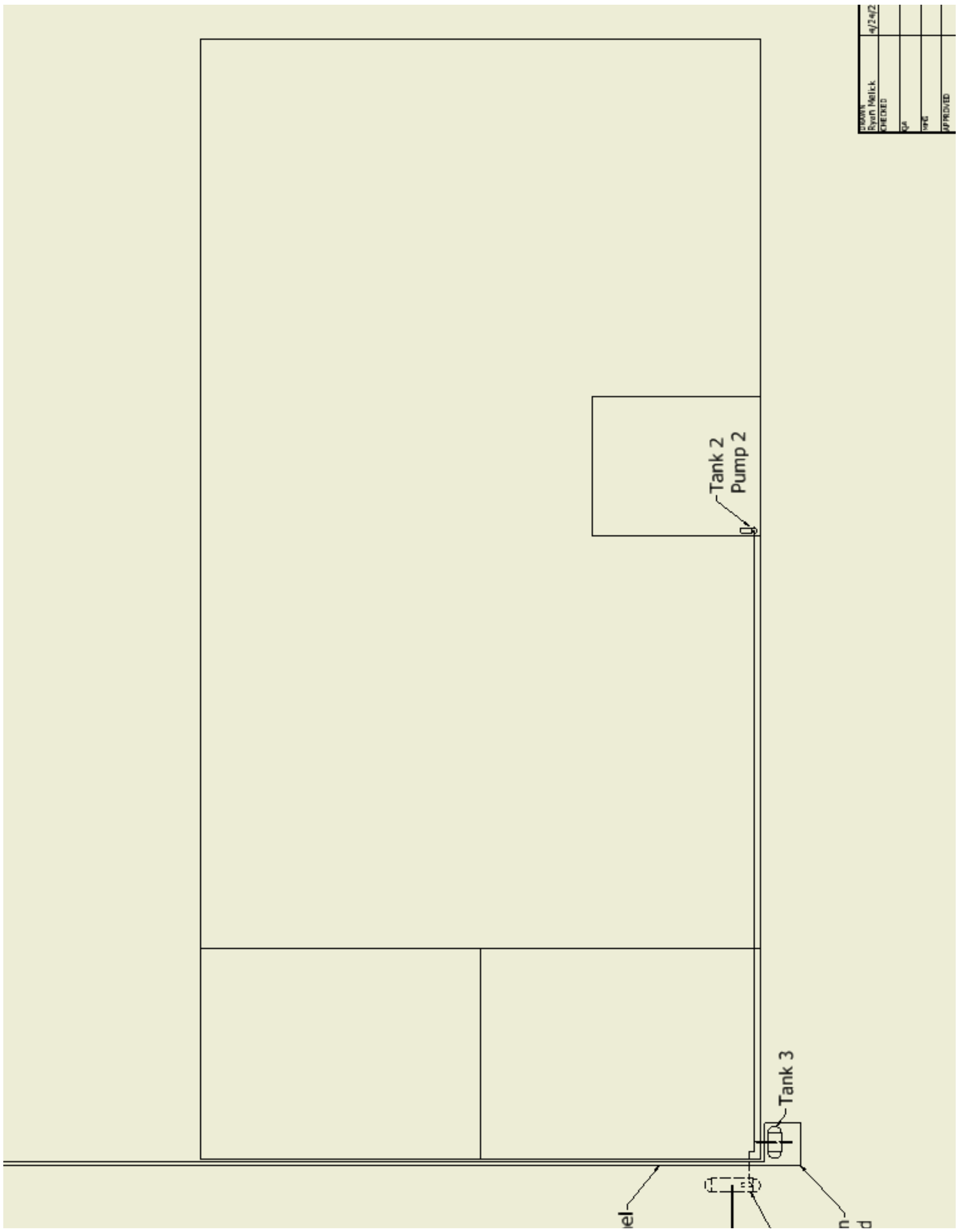


Figure 3.7.1

3.7.2. Elevations Drawing

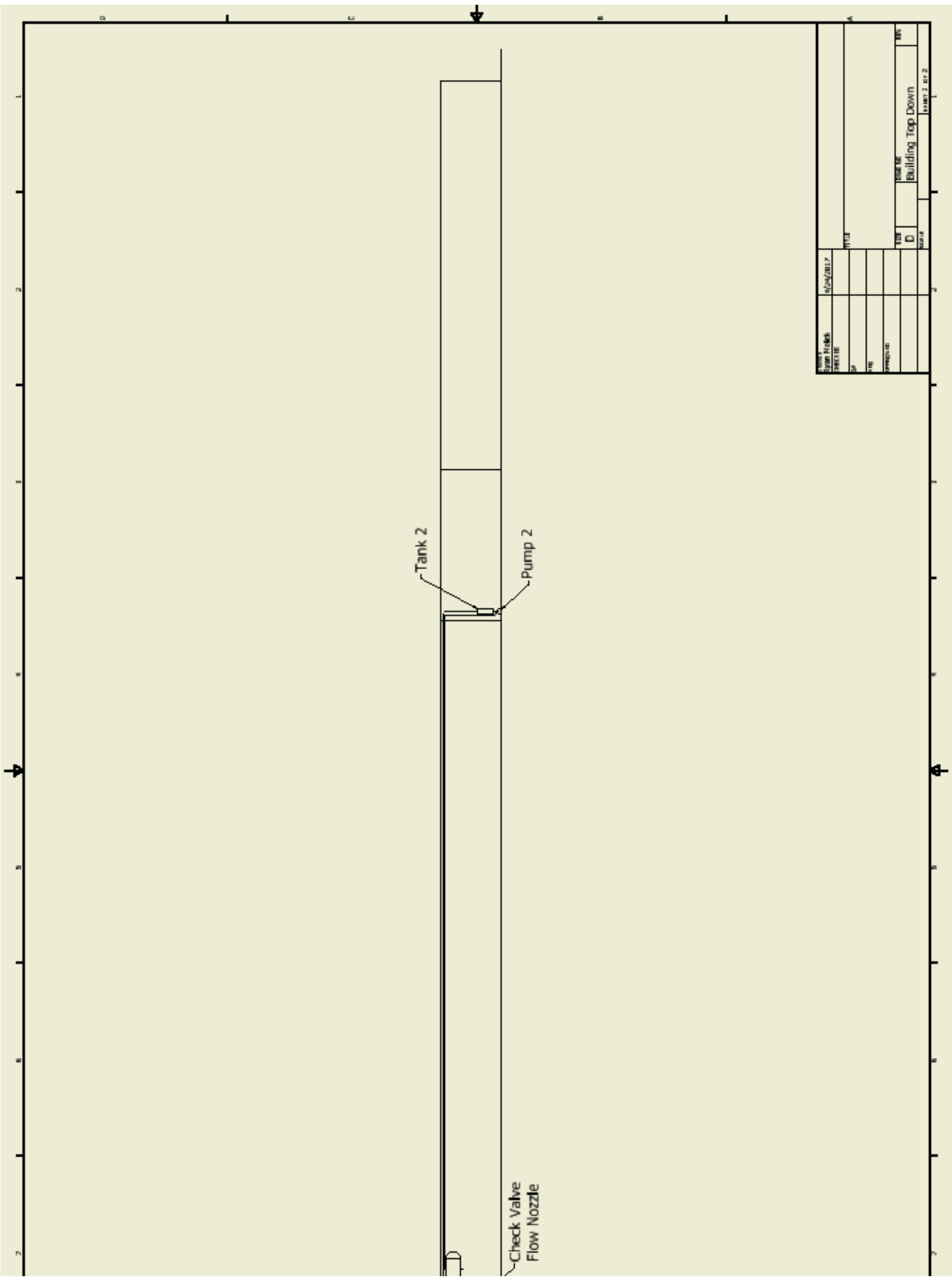


Figure 3.7.2

3.7.3. Isometric Drawings

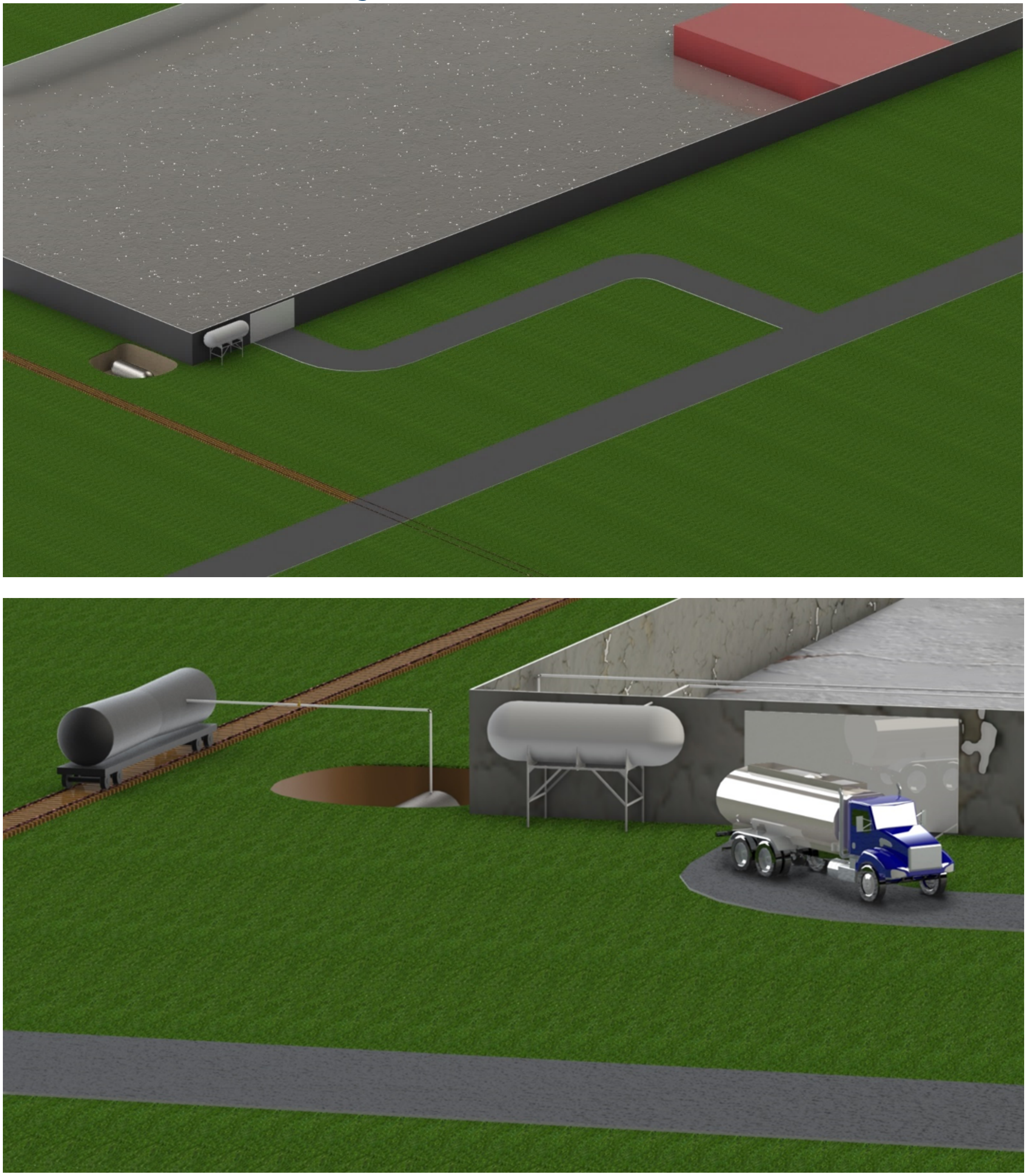


Figure 3.7.3.1

Figure 3.7.3.2

Isometric drawings are not to scale

3.8. Bill of Materials

All pipe and fitting sizes are nominal, schedule 40.
All pipes, fittings, and tanks are to be composed of ASTM A106 steel

	Size	Qty (ft)
Pipe	1.5in	589.3
	3.5in	13
	4in	43

Table 3.8.1

	Size	Component	Qty.
Fittings	1.5in	Elbow	10
		Ball Valve	4
		Check Valve	2
		Gate Valve	1
		Flow nozzle	1
		Manometer	1
	3.5in	Elbow	2
		Gate Valve	1
	4in	Elbow	2
		Gate Valve	1
		Flange	1

Table 3.8.2

		Dia. (ft)	L (or H) (ft)
Tanks	T1	9.906	30
	T2	4.073	11
	T3	9.906	13.6

Table 3.8.3

		Sulzer part no.
Pumps	Pump 1	3 x 4 x 8B-1 OHH
	Pump 2	3 x 4 x 4 x 11.5 - 1 OHH

Table 3.8.4