ME 4465 Project #2 Memo

MEMO

To: Professor Mary Hofle

From: Sayler Massey, Matthew Wright, Shishir Kanal

Memo generated by: Sayler Massey

Date: October 18, 2018

Subject: ME 4465 Design Summary for Project # 2 – Pump and Piping System Design

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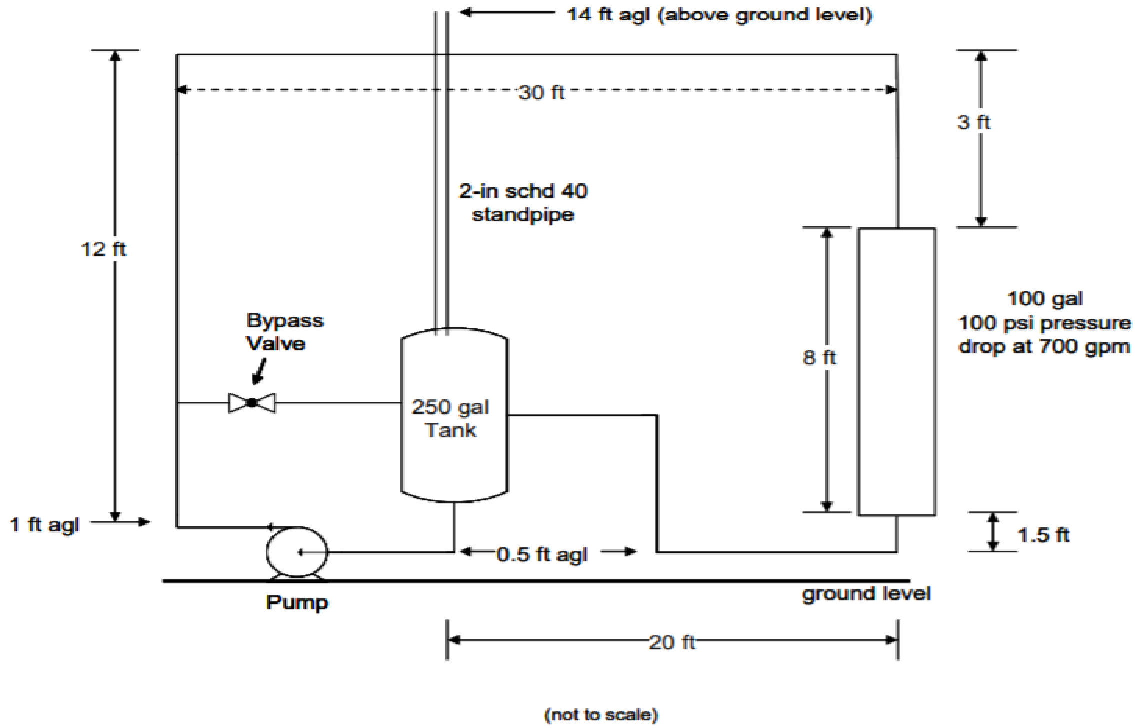
Summary of Design

Introduction: Our team of design engineering students has been tasked to design a piping system to handle the pressure drop. Deliverables include a layout of the design (as a Solidworks drawing), verification of maximized efficiency and minimized power, charts to support conclusions, a table of loss coefficients for all values, references including pump information, and calculated proof our design meets the requirements.

System Requirements: The given design must be capable of overcoming a pressure drop of 100 psi and a flow rate of 700 gpm. The velocity should not exceed 15 ft/s and schedule 40 pipe must be used. The pump must be centrifugal and Bell and Gosset or equivalent. The pump must heat the water from 50°F to 140°F. A drawing of the current given design is shown below.



Objective: The objective is to design a piping system capable of overcoming a pressure drop of 100 psi and a flow rate of 700 gpm. An ideal system will maximize the efficiency of the pump and minimize the power intake of the pump. Several pumps shall be compared to demonstrate that a maximum value was found.

Results:

We chose pump Bell and Gossett Pump # e1510 series- 3BD. Our Pipe diameter was developed in the fluid properties section, NPSH in the NPSH section, Flow Velocity in the fluid properties section, Pump head in the Pump section, and water heating time in the Time section.

Description	Value	Necessary	Check
Pipe Diameter	5.047 inches	N/A	Good
NPSHA	32.48 feet	<20.4 feet	Good
Flow Velocity	11.22 ft/s	>15 ft/s	Good
Pump Head	282 feet	>255 feet, 113 psi	Good
Water Heating Time	2.79 hours	A reasonable time	Good

Conclusion: Our design met the stated requirements as demonstrated. Our final flow velocity was 11.22 ft/s, which is lower than the required 15 feet/s (developed in section 2 of fluid properties MATLAB coding). Our pump could deliver a maximum pump head of 282 feet (developed in section Pump information), which was greater than the total pressure drop of 113 psi (developed in Bernouilli's equation, fluid properties). Our $NPSH_a$ was equal to 32.48 feet, which was greater than $NPSH_R$ developed of 20.4 feet, developed in section NPSH. The total time required for the pump to heat the water from 50 ° F to 140 ° F was 2.79 hours (developed in section Time).

Report

Requirements:

The design project was broken down to 3 sections namely section 1, 2 and 3. Section -1 required that a piping system is designed which incorporates a reservoir and a pump. The fluid velocity should not exceed 15 ft/s. The system should also overcome the pressure of 100 psi at 8 ft section of the pipe. Schedule 40 pipe needed to be used for the design.

An appropriate pump was required to fit the system that would connect the pipes coming out and going into the reservoir on section-2. Also, it was required that the pump works without cavitation by analyzing the suction heads.

On section -3 it was required that the time required to increase the temperature of the water due to the dissipation of the heat from the pump from 50 F to 140 F. Time required to heat the water to 90 F was required. No heat loss condition was imposed.

Givens:

For the section -1, a maximum flow velocity condition of 15 ft/s was given. Also, the flow velocity of 700 gpm was provided. It was also provided that an 8 ft section would need to overcome a pressure of 100 psi.

In section 2, atmospheric pressure of 12.5 psia was provided.

In section-3, the temperature difference for which the time required to heat the water which was 50 F to 140 F was provided. A temperature value 90 F was also provided.

Determine:

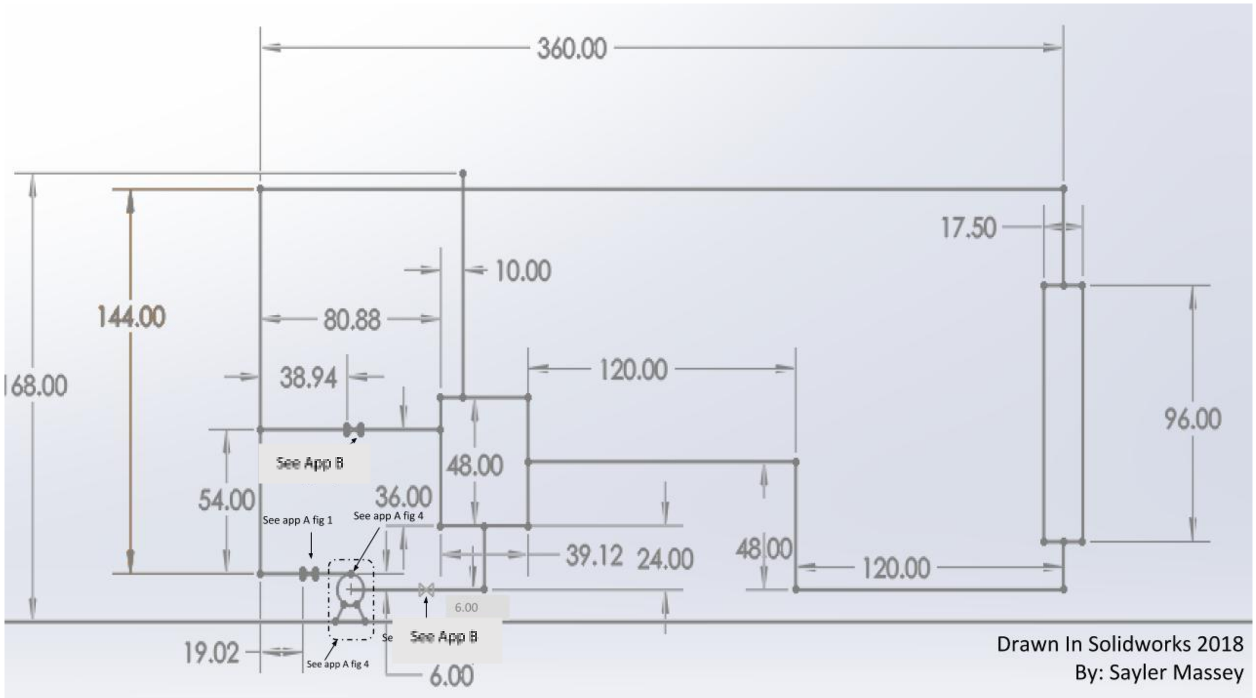
Section-1 of the project required that the diameter of the pipe was to be determined that would meet the criteria provided. The determination process required the calculation of the Reynolds number, friction factor, friction loss, minor loss and total head loss.

Section -2 required to determine the NPSHA available, NPSHA required. Efficiency highest for a lowest power requirement was required to be tracked from the pump performance curve.

In section-3, the power value of the pump chosen was taken and the power was calculated using hydraulic horsepower and using that the time was found to be 2.79 hours to raise the temperature 90 degrees F.

Design:

Annotated Piping Overlay:



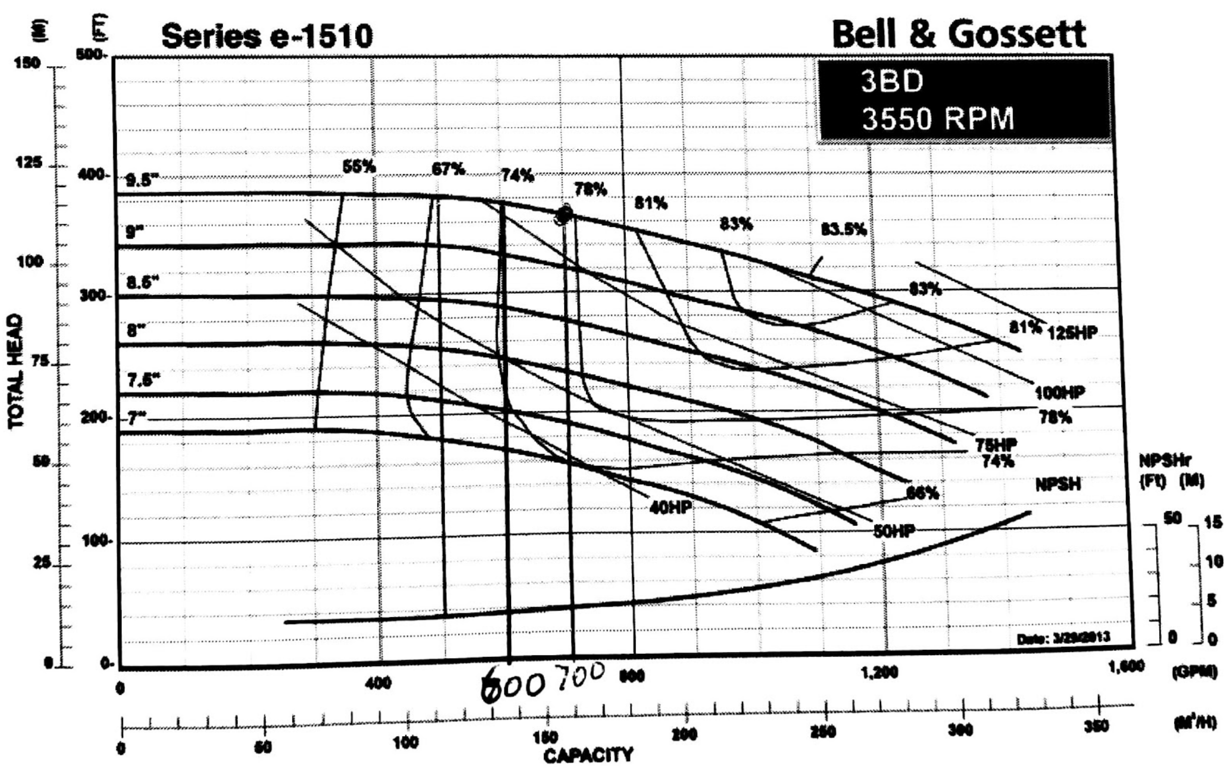
An annotated PNID with dimensions (in inches) is shown above. Further call outs of systems can be seen in appendix A.

Pump information:

Our final pump chosen was Bell and Gossett Pump # e1510 series- 3BD. It has a duty cycle power output of 57 hp, a NPSH of 32 feet (which was greater than the required NPSH of 20.4), has a max flow rate of 1600 GPM (greater than the required 700), a shutoff head of 282 feet, a max efficiency of 77.7% at 700 gpm. Shown below are comparable pumps with efficiency curves and data. This pump is hooked into the piping system using an expansion joint to expand the inlet and discharge from 4 in nominal and 3 in nominal respectively to 5-inch nominal (system piping diameter), which is shown in appendix A figure 4. This compares favorably to the other pumps, which have an efficiency of 72.6% for pump 4BD, 73.7% for 4EB, and 72.8 % for 3EB . The duty power for our pump was 57.4, which is the lowest power consumption out of comparable pumps in the 1510 series, with a 61 hp for pump 4BD, 61.5 for 4EB, and 60.7 for pump 3EB. Because our pump has a higher efficiency and lower required power than other sufferable pumps our pump is the best pump to go with. This is demonstrated in the below chart. Chart data was completed by Matthew Wright in Excel.

e-1510 series	RPM	Impeller (in)	height discharge (in)	suction (in)	height(in)	flows (gpm)	NPSHr (ft)	efficiency %	shutoff head (ft	Power (HP)	Max power (HP)	Duty point (HP)
3BD (variable speed, 60Hz)	3600	8.25	20.75	13.25	22.5	**700**	20.4	77.7	282	75	68.3	57.4
						525	13.2	75.6				30.4
suction diameter (in) = 4						**350**	8.15	71				14.7
discharge diameter (in) = 3						**175**	5.44	55.6				6.85
4BD (variable speed, 60Hz)	3600	8.25	24.5	16.5	26.75	**700**	18.8	72.6	263	100	81.6	61
						525	12.5	69.4				33.2
Suction (in) = 5						**350**	8.36	62.4				16.8
Discharge (in) = 4						**175**	5.95	47.3				8.05
4EB (constant speed, 60Hz	3600	8.375	26.25	16.5	26.75	**700**	27.9	73.7	278	75	73.3	61.5
Suction (in) = 5												
Discharge (in) = 4												
3EB (variable speed, 60Hz)	3600	9	23.5	14	23.5	**700**	17.1	72.8	268	75	66.7	60.7
						525	10.9	72.3				31.8
Suction (in) = 4						**350**	6.64	69.7				15
Discharge (in) = 3						**175**	4.32	57.8				6.54

Pump efficiency Curve for the chosen pump with efficiency at 700 gpm marked as 77.7%, similar to the above referenced chart.



Fluid Properties:

MATLAB Code:

Our MATLAB code was developed by Matthew Wright and Shishir Kanal. Part I uses the flow rate and the velocity to develop the pipe diameter, which is then referenced against the crane manual to find the minimum pipe diameter nominal sizing, which came out to be 0.42 feet of 5 inches, as shown in the values output chart as pipediaavailable.

```
%Shishir Khanal
%ME 4465; Project - 2
%Group Partners:
%      Sayler Massey
%      Matthew Wright
% Purpose of the code:
%    Part-I: Determine minimum Diameter
%    Part - II: Calculate the Actual Velocity
%    Part-III: Calculate Reynolds Number
%    Part-IV: Friction Factor calculation
%    Part V: Minor Loss Calculation
%    Part VI:Calculate the friction loss
%    Part VII:Haaland and minorloss functions
%    Part VIII:Calculation of total Reduction loss due to Pump
%-----------------------------------------------------------
clear;
clc;
%clears the worksheet and command screen

%-----------------------------------------------------------
%Part-I: Determine minimum Diameter
FlowRate = 1.559;
% Q = 700 gpm ; 1 gpm = .00223 ft^3/s
vel = 15;
% Optimum velocity used
PipeDia = sqrt((4*FlowRate)/(vel*pi));
% this is the minimum size pipe that meets the requirements
PipeDiaAvailable = 0.4206;
% this is the inner diameteravailable sch 40 size pipe
% 0.4167 is the nominal diameter of pipe used
%----------------------------------------------------------
```

Part II then takes the same equation used above, Q=VA and uses the known values of A and Q from Part I to develop the actual pipe flow velocity, which was 11.22 ft/s, shown in the values output chart as velactual.

```
%Part-II: Calculate the Actual Velocity

 velActual = FlowRate/((pi/4)*PipeDiaAvailable^2);
%Actual velocity calculated using the new diameter with same flow rate
% v=Q/A; A = (Pi/4)*D^2
```

Part III then calculates the Reynolds number using the equation Re=ρV*D/μ, where Re is the Reynolds Number, ρ is the density of the water, 62.4 lb/ft^3, V is the velocity at 11.22 ft/s, D is the pipe diameter of 5 in. and μ is the dynamic viscosity, which is 0.0008791. This gives us a Reynolds number of 3.3*10^5.

```
%Part-III: Calculate Reynolds Number
Density50F = 62.47;
%Density of water at 50F(lbm/ft^3)
%this was chosen considering the maximum density at 50F (50F-140F)range
CoefDynaVisc = 8.791*10^-4;
%(lbm/(ft*s))
ReynoldNum = Density50F*velActual*PipeDiaAvailable/CoefDynaVisc ;
%Unitless
```

Part 4 Calculates the friction factor using the Haaland equation (from Munson 7th page 431 eqn 8.35b):

1/√λ = -1.8log [(6.9/Re) + ((Ks/d) / 3.7)1.11)

The epsilon factor of 0.00015 ft (from https://www.pipeflow.com/pipe-pressure-drop-calculations/pipe-roughness), the pipe diameter of 5 in (shown in part 1), and the reynolds number of 3.3*10^5 (part 3). Our final friction factor was 0.0170.

```
% Part-IV: Calculate Friction factor

 epsilon = 0.00015;
%Chosing material to be Common Steel(e=0.00015 ft)
FrictionFactor = Haaland(epsilon,PipeDiaAvailable,ReynoldNum);
%Friction factor calculation through the function
%-------------------------------------------------------------
```

Part 5 caluclates the minor loss values. These loss values were taken from (http://www.metropumps.com/ResourcesFrictionLossData.pdf as shown in Appendix A figure 4). These values are then summed up to give a final minor loss value of 33.59 feet.

```
% Coefficients for minor loss Vaiues for
% 90 deg elbows (long Radius) = .34(*7)
% Gate Valve(Swing) = .13
% Check Valve = .825
% Screwed Fittings = .72
% Entry loss(Sharp Edged) = 0.5(*3)
% Exit loss(Sharp Edged) = 1(*3)
% T-joint = .32
kSum = .72+.825+(7*.34)+.13+(3*0.5)+1*3+KredExp(FrictionFactor)+.32;
%sum the minor loss coeficients
LossMinor = minorloss(kSum, vel);
%Calculate the minor loss from the minorloss function
```

Part 6 calculates the head loss by adding the minor losses, the section head loss, and the elevation loss. The friction loss was calculated using the friction loss equation from ELEPANT

$$Frictionloss = f * L * \frac{v^2}{2gD}$$

Where f is the friction factor, L is the length (83.67 feet), v is the velocity, 11.22 feet/s (part 2), D is the diameter of 5 in (part 1), and g is the gravitational force of 32.2 ft/s^2. The headloss suction is 230.73 feet and the elevation difference between the inlet and outlet of the pump is 6 inches. These values sum to be 276.66 feet of head loss.

```
%Part-VI: Calculate the Headloss loss
Length = 83.67;
g=32.2;
FrictionLoss = ((FrictionFactor*Length*(vel)^2)/(.4206*2*g));
%Friction loss for the length of the pipe except
HeadlossSection = 230.73;
% Head loss due to the pressure change i the 8 ft section
ElevationDiff = 0.5;
%change in elevation of the inlet and outlet of the pump
HeadlossTotal = FrictionLoss+ LossMinor+HeadlossSection+ElevationDiff;
%Frictionloss throughout the length of the pipe
%Minor losses due to fittings
%----------------------------------------------------------
```

Part 7 calculates the minor losses again to reiterate the friction factor found in part 4, using the same equations.

```
%Part VII: Haaland and minorloss functions
function FrictionFactor = Haaland(epsilon,PipeDia,ReynoldNum)
%Haaland Equation to calculate the friction factor
 %   Haaland equation to calculate the friction factor
% Input Variables = Reynolds Number, Epsilon = Relative Roughness of the
%                   pipe surface and the Diameter of the pipe
% Output Value = friction factor
term1 =((epsilon/PipeDia)/3.7)^1.11;
term2 = (6.9/ReynoldNum);
FrictionFactor = 1/(-1.8*log10(term1+term2))^2;

end

function MLoss = minorloss(flowCoeff, velocity )
%UNTITLED Summary of this function goes here
%   Calculates the minor loss
% units in British Units
acelgr = 32.2 ;
MLoss = (flowCoeff*(velocity)^2)/(2*acelgr);
end
```

Part 8 runs a simple function on the friction factor to calculate the K reduction loss factor of the pump based on the inlet and outlet sizes of the pumps. Reduction values were taken from the e1510 3ed pump specifications.

```
%----------------------------------------------------------
% Part VIII: Calculation of total Reduction loss due to Pump

function RedExp = KredExp(frictionfactor)
%UNTITLED Summary of this function goes here
```

```
%   Calculates the reduction and expansion losses
% units in British Units
D1Red = 5.046;
D2Red = 4.026;
D1Exp = 3.068;
D2Exp = 5.046;
Kred = (0.6+0.48*frictionfactor)*(D1Red/D2Red)^2*(((D1Red/D2Red)^2)-
1)*sqrt(sin(pi/8));
Kexp = (1+(0.8*frictionfactor))*(1-(D1Exp/D2Exp)^2)^2;
RedExp = Kred + Kexp;

end
```

Below the final output values of this code can be seen.

Workspace

Name	Value
CoefDynaVisc	8.7910e-04
Density50F	62.4700
ElevationDiff	0.5000
epsilon	1.5000e-04
FlowRate	1.5590
FrictionFactor	0.0170
FrictionLoss	11.8412
g	32.2000
HeadlossSection	230.7300
HeadlossTotal	276.6645
kSum	9.6151
Length	83.6700
LossMinor	33.5933
PipeDia	0.3638
PipeDiaAvailable	0.4206
ReynoldNum	3.3537e+05
vel	15
velActual	11.2206

Hand Calculations:

Minor Losses:

We developed the equations used for minor losses from Munson Fluid Mechanics 7th. The governing equation is $H_{Lmin} = K_L * \frac{V^2}{2g}$, which can be found on page 443. Calculations were done by Shishir Kanal.

Minor Loss Calculation

K_m for Globe valve = 7.1

K_m for Gate Valve (Swing type) = .13

Other fittings chosen based on the requirement of change in direction of pipe.

Hence, Gate valve is used for the purpose

$\Sigma K = 9.6151$

h_m = minorloss (9.6151, 11.22) = 18.7977 ft

The given values for the gate valve and globe valve are shown below, as described in Appendix A figure 4

Major Losses:

Following this we calculated the head loss as demonstrated below. The governing equation is $H_{Lmajor} = f * \frac{L}{D}\frac{V^2}{2g}$ where HL is the head loss, f is the friction factor (developed from the Haaland equation, see part 4, fluid properties), L is the length of the pipe, calculated from the dimension diagram above, the pipe diameter developed using MATLAB coding (see part 1, fluid properties), v is the pipe velocity, given by the equation Q=VA and calculated below and in part 2 of the MATLAB coding, where Q is the given flow rate, 700 gpm, and A is the Area, developed from the equation $A = \pi r^2$, using the diameter calculated below (see part 2 of MATLAB coding).

Head Loss Calculation

$h_f = f \frac{L}{D} \frac{v^2}{2g} = 11.8412 \text{ ft}$

$z_2 - z_1 = 0.5 \text{ ft}$

h_L due to section $= \frac{\Delta P}{\gamma}$

$= \frac{100 \text{ lbf in}^{-2}}{62.4 \text{ lbf ft}^{-3}} \times \frac{144 \text{ in}^2}{1 \text{ ft}^2}$

$\therefore h_{L_{sec}} = 230.73 \text{ ft}$

length of pipe = 83.67 ft

$g = 32.2 \text{ ft s}^{-2}$

$v = 11.22 \text{ ft s}^{-1}$

$D = 0.4206 \text{ ft}$

Bernoulli's Equation to find overall pressure drop:

Here we used Bernoulli's equation pulled from (Munson 7th page 294 eqn 6.58). The equation can be seen below, which is $\frac{P_1}{g} + \frac{V1^2}{2g} + Z_1 = \frac{P2}{g} + \frac{V2^2}{2g} + Z2$. We then used the total head loss and height drop to calculate the total change in pressure of the system. Velocities are taken from part 2 of the MATLAB coding and using Q=VA, which is further developed above.

Modified Bernoulli's,

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + h_f + h_m$$

$$\frac{P_1 - P_2}{\rho g} = z_2 - z_1 + h_f + h_m$$

$\therefore$ For system $h_L = 0.5 ft + 11.8412 ft + 18.7927 ft = 31.14 ft$

Also, the section has a significant head loss.

So, $h_{L_{Total}} = h_{L_{sec}} + h_{L_{syst}} = 230.73 ft + 31.14 ft = 261.87 ft$

$$h_{L_{Total}} = \frac{\Delta P}{\gamma}$$

$\therefore \Delta P = 261.87 ft \times 62.41 \, lbf \, ft^{-3} \times \frac{1 ft^2}{144 in^2} = 113.5 psi$

Diameter: The flow rate was calculated using Q=VA, using the given values of Q = 700 gpm, and a max velocity of 15 ft/s. From here the total diameter is calculated and then a normal size is found in the crane manual and the calculated velocity is retroactively found. This backs up the information found in MATLAB coding section 1.

* Flow Rate,

$Q = VA$

$1.559 \, ft^3/s = 15 \, ft/s \times \frac{\pi}{4} \times D^2$

$\therefore D = \sqrt{\frac{4 \times 1.559}{15 \pi}} = 0.3638 \, ft$

The schedule 40 pipe that will not exceed the velocity will have the diameter just greater than D.

$\therefore D = 0.4206 \, ft$ (i.e. 5.047 in)

Flow Velocity: The flow velocity was then calculated by taking this value of the area based on a 5 in diameter and 700 gpm, which gave a max velocity of 11.22 ft/s. The equation used was Q=VA, found in Munson 7th fluid mechanics eqn 3.18 pg. 120. This backs up the MATLAB coding section 2

Calculating the actual velocity

$$Q = vA$$

$$1.559\ ft^3 s^{-1} = v \times \frac{\pi}{4} \times (0.4206\ ft)^2$$

$$\therefore v = 11.2206\ ft\, s^{-1}$$

Reynolds Number: From there the Reynold's number was found using the equation Re=ρV*D/μ, where Re is the Reynolds Number, ρ is the density of the water, 62.4 lb./ft^3, V is the velocity at 11.22 ft/s, D is the pipe diameter of 5 in. and μ is the dynamic viscosity, which is 0.0008791. This gives us a Reynolds number of 3.3*10^5. This backs up the MATLAB coding section 3 above.

* Reynold's number

$$Re^{\#} = \frac{\rho v D}{\mu}$$

$$\therefore Re^{\#} = 3.354 \times 10^5$$

$$\rho_{w_{50°F}} = 62.47\ lbm\ ft^{-3}$$

$$v = 11.2206\ ft\, s^{-1}$$

$$D = 0.4206\ ft$$

$$\mu = 2.730 \times 10^{-5}\ lbf\, s\ ft^{-2} \times \frac{32.2\ lbm\ ft\, s^{-2}}{1\ lbf}$$

$$\therefore \mu = 8.791 \times 10^{-4}\ lbm\ ft^{-1} s^{-1}$$

Friction Factor: The friction faction is developed using factors found in Appendix A figure 4 The epsilon is found using a common steel, which is good enough because we are not using an expensive pipe with a low surface friction factor. The Haaland equation: 1/√λ = -1.8log [(6.9/Re) + ((Ks/d) / 3.7)1.11) from Munson 7th pg. 431 is used to develop an overall friction factor.

* Friction factor
* New Riveted steel ($\epsilon = 0.01\ ft$) [Source: Notes]
  Haaland (0.01 ft, 0.4206 ft, 3.354×10^5) => 0.0522
* New Common steel ($\epsilon = 0.00015\ ft$) [Source Notes]
  Haaland (0.00015 ft, 0.4206 ft, 3.354×10^5) => 0.0170
* We do not need an expensive pipe with very low surface roughness. So the New common steel is good enough to meet the purpose. We selected steel from steel & iron who had the same 'ε' because of it's strength.

\

Thus, the hand calculations and coding done by Shishir Kanal and summed by Sayler Massey demonstrates the fluid properties necessary.

NPSH Sections:

MATLAB Coding:

Developed by Matthew Wright.

NPSHa is needed to be known to choose a pump that will perform the necessary requirement without cavitation happening inside. NPSHa was calculated using $NPSHa = \frac{P_{atm}}{\gamma} - z_1 - h_l - \frac{P_v}{\gamma}$

Where $P_{atm} = atmospheric\ pressure$

$\gamma = specific\ weight$

$h_1 = headloss\ of\ system\ from\ free\ surface\ to\ pump\ entrance$

$P_v = vapor\ pressure$

The head loss of the system from the free surface to the pump entrance is needed. It was calculated in two sections. This first section is the loss from the 7 feet of 5in nominal diameter pipe.

```
%Matthew Wright NPSHa headloss
clear;
clc;
%Finding the losses for NPSHa calculation
%Nominal pipe size of 5in
%Dnom = 5.047;
%gravity is in in/s
g = 386.4;
first = 'what is the pipe size ?'; %5.047in
Dlg = input(first);
Dlgft = Dlg/12;
%using standard steel pipe
epsi = .00015;
%Velocity is inches per second
V1 = 134.64;
%V1 = 53.85
%Reynolds number, everything in terms of inches
%L is lenght of pipe section
second = 'how long is the section of pipe ?'; %84 inches
L1 = input(second);
Re = (.036*V1*Dlg)/(7.318*10^-5);
ED1 = epsi/(Dlgft);
f = haaland(ED1,Re);

hf = f*(L1/Dlg)*((V1^2/(2*g)));
```

The next section calculated the K values for the reduction, elbow, tank exit and pump entrance.

```
%smaller diameter of pipe, input to pump

third = 'what is the smaller pipes diameter? \n If it is the same size say give that si
is the pump suction size';
Dsm = input(third);
Dsmft = Dsm/12;
fourth = 'What is the length of the smaller pipe in inches?';
ED2 = epsi/(Dsmft);
L2 = input(fourth);
V2 = 211.62;
Re = (.036*V1*Dsm)/(7.318*10^-5);
f2 = haaland(ED2,Re);
%hf2 = f2*(L2/Dsm)*((V2^2/(2*g)));
%hft = hf+hf2;
%Find K losses for pipe
Kelb = .255;
%gate valve
Kvalve = .13;
%Tapered Reduction at 45 degrees
Kr = (.6+.48*f)*(Dlg/Dsm)^2*((Dlg/Dsm)^2-1)*.6186;
Kexit = .5;
Ksum = Kelb+Kvalve+Kr+Kexit;
%Ksum = Kelb+Kvalve+Kexit;
hminor = Ksum*(V1^2/(2*g));
%head loss in feet
%htotal = (hf+hf2+hminor)/12
htotal = (hf+hminor)/12
```

The total head loss of that pipe section is 2.945 ft including minor losses as seen in the results Table. Appendix A figure 4. The minor loss coefficients were found from metropumps.com/resourcesfrictionlossdata.pdf and the reduction loss coefficient K= $(.6 + .48f)\left(\frac{Dsm}{Dlg}\right)^2\left(\left(\frac{Dsm}{Dlg}\right)^2 - 1\right) * \sqrt{sin(\frac{\theta}{2})}$ where theta was chosen to be 45 degrees.

When the headloss is known it can be plugged into the NPSHa equation from above as seen below.

The density of 1.908 slug/ft^3 multiplied by gravity, vapor pressure of 416.61 lb./ft^2, Q of 1.559ft^3/s, a height below the free surface of 12.625 ft at atmospheric pressure at 1800lb/ft^2 resulted in a NPSHa of 32.3191 feet. This is only one condition however and a full list of all values for all iterations run for both calculations can be found at the end of this description. Tables of iterations run for the four pumps, 3BD, 3ED, 4EB, 4BD.

2.945
0

```
%NPSHa with known inlet velocity
%Density of water is at 50 degrees F
% Pi (inlet pressure), lb/ft^2
Pi = 1800;
%density , slug/ft^3
den = 1.908;
%gravity ,ft/s^2
g = 32.2;
%vapor pressure of water lb/ft^2
Pv = 416.61;
%Q = flow rate, CFS
Q = 1.5596;
% d= diameter of suction(inlet), ft
d = .25;
% inlet area
A = (3.14*d^2)/4;
%Vi = suction(inlet) velocity, A is inlet area
Vi = Q/A;
%Vi = 15

%zi = height of pump above reservoir free surface, ft
zi = 12.625;
%hfi = head loss in piping between reservoir and pump, ft (from other code)
hfi = 2.844;
%atmospheric pressure, lb/ft^2
Pa = 1800;
%specific weight of water ,lb/ft^3
gamma = 61.38;
%NPSHa from class notes (feet of head available)
NPSHa = (Pa/gamma)+zi-hfi-(Pv/gamma)


 %from bottom of tank to the entrance of the pump in hfi

>>
```

The full lists of values used in the calculations and results from those calculations. The calculations were run for all four pumps being compared however pumps 4BD and 4EB both achieved the same results.

Pump 3BD values

Name	Value
A	0.0491
d	0.2500
den	1.9080
Dlg	5.0470
Dlgft	0.4206
Dsm	4.0260
Dsmft	0.3355
ED1	3.5665...
ED2	4.4709...
epsi	1.5000...
f	0.0170
f2	0.0179
first	'what is...
fourth	'What i...
g	32.2000
gamma	61.3800
hf	6.6533
hfi	2.9450
hminor	28.6862
htotal	2.9450
Kelb	0.2550
Kexit	0.5000
Kr	0.3379
Ksum	1.2229
Kvalve	0.1300
L1	84
L2	0
NPSHa	32.4681
Pa	1800
Pi	1800
Pv	416.6100
Q	1.5596
Re	2.6666...
second	'how lo...
third	'what is...
V1	134.6400
V2	211.6200
Vi	31.7880
zi	12.8750

Pump 3EB values

Name	Value
A	0.0491
d	0.2500
den	1.9080
Dlg	5.0470
Dlgft	0.4206
Dsm	4.0260
Dsmft	0.3355
ED1	3.5665...
ED2	4.4709...
epsi	1.5000...
f	0.0170
f2	0.0179
first	'what is...
fourth	'What i...
g	32.2000
gamma	61.3800
hf	6.6533
hfi	2.9450
hminor	28.6862
htotal	2.9450
Kelb	0.2550
Kexit	0.5000
Kr	0.3379
Ksum	1.2229
Kvalve	0.1300
L1	84
L2	0
NPSHa	32.4231
Pa	1800
Pi	1800
Pv	416.6100
Q	1.5596
Re	2.6666...
second	'how lo...
third	'what is...
V1	134.6400
V2	211.6200
Vi	31.7880
zi	12.8300

4EB and 4BD values

Name	Value
A	0.0491
d	0.2500
den	1.9080
Dlg	5.0470
Dlgft	0.4206
Dsm	5.0470
Dsmft	0.4206
ED1	3.5665...
ED2	3.5665...
epsi	1.5000...
f	0.0170
f2	0.0170
first	'what is...
fourth	'What i...
g	32.2000
gamma	61.3800
hf	6.6533
hfi	2.8440
hminor	20.7599
htotal	2.2844
Kelb	0.2550
Kexit	0.5000
Kr	0
Ksum	0.8850
Kvalve	0.1300
L1	84
L2	0
NPSHa	32.3191
Pa	1800
Pi	1800
Pv	416.6100
Q	1.5596
Re	3.3429...
second	'how lo...
third	'what is...
V1	134.6400
V2	211.6200
Vi	31.7880
zi	12.6250

3BD Variable speed 60 Hz info	**e-1510 series**	**700gpm**					
	suction height (in)	NPSHa (ft)	NPSHr (ft)	Total Head loss (ft)	Shutoff head	Headloss Check	pump max flow rate
suction = 4in	13.25	32.4891	20.4	256.1785	282	256 < 282, good	1600 gpm > 700gpm
discharge = 3in							
4BD Variable speed 60Hz							
	suction height (in)	NPSHa (ft)	NPSHr (ft)	Total Head loss (ft)	Shutoff head	254.99 < 263, good	2000gpm > 700gpm
suction = 5in	16.5	32.4511	18.8	254.9952	263		
discharge = 4in							
4EB Constant speed 60Hz							
	suction height (in)	NPSHa (ft)	NPSHr (ft)	Total Head loss (ft)	Shutoff head	254.99 < 273 good	1600gpm >700gpm
suction = 5in	16.5	32.4511	27.9	254.9952	278		
discharge = 4in							
3EB Variable speed 60Hz							
	suction height (in)	NPSHa (ft)	NPSHr (ft)	Total Head loss (ft)	Shutoff head	256.99 < 268 good	1250gpm > 700gpm
suction = 4in	14	32.4231	17.1	256.1785	268		
discharge = 3in							

Another table of some iteration values of the pump. Every pump is more than qualified to run the system having meet the flow requirement and is below the NPSHa. The pump curve in the pump information and appendix A figure 5.

The pump selected was the 3BD, because of its higher efficiency and lower power requirements compared to the other selected pumps as seen in the pump efficiency curves in the pump properties.

A requirement that the water needed to be heated was addressed once the pump was chosen. The time to find the time required to head the water was solved using two main equations. $P_w = Q\Delta P$ which give the hydraulic horsepower needed for the system and $\dot{Q} = \dot{m}C_p\Delta T$ that gives the power transfer rate. The full calculation is shown below and solving for the time.

```
%Matthew Wright
%Heat calculations
%Time required to heat the water in the system
deltaT = 90; %degrees F
Cp = 1; %Btu/lb*R
Qdot = 1.559; %ft^3/s
volumeTank = (100 +250)/7.481; % ft^3
volumePipe = (pi/4)*((.1723^2)*14+.4206^2*75.67);
Vtot = volumeTank+volumePipe;
Mwater = 62.4*Vtot;
deltaP = 16012.66; %lb/ft^2 = 111.199 psi
Pw = Qdot*deltaP; %hydraulic horse power
%mdot = Mwater/t;
%convert Pw into BTU to match units with Cp
% 1 BTU = 778.2 lbf*ft
PwBTU = Pw/778.2;


%Equation for heat trasfer
% mdot*Cp*deltaT = Pw
t = (Mwater*Cp*deltaT)/PwBTU; %seconds
tHours = t/3600 %total time in hours
```

```
>> Heating_time_proj_2

tHours =

    2.8023

>>
```

The volume of the system was found for both the water in the pipes as well as in the tanks giving a value of 57.33ft^3. Using the volume and the density the mass of the water was found and that was used in the equation for the power transfer rate. The hydraulic horsepower was converted to BTU's and then was used to divide the value of the water mass, specific pressure and temperature change to find a time of 10088 seconds which reduces to 2.8 hours. All the values used in the calculation is in a list below.

Name	Value
Cp	1
deltaP	1.6013...
deltaT	90
Mwater	3.5958...
Pw	2.4964...
PwBTU	32.0788
Qdot	1.5590
t	1.0088...
tHours	2.8023
volumePipe	10.8400
volumeTank	46.7852
Vtot	57.6252

Hand Calculations to back up coding:

Performed by Matthew Wright.

NPSHA Headloss Calculation:

The length of the piping from the bottom of the tank to the entrance of the pump is 84 inches. The equation used for NPSHA is found on page 683 Cengel where Patm is the atmospheric pressure 1800 lb/ft^2 (from given), γ is the specific weight of the fluid, 61.44 lbm/ft^3, Z1 is the distance between the free surface and the pump inlet, hl is the head losses between the free surface and the pump inlet, Pv is the vapor pressure.

$$NPSHA = \frac{atm}{} - Z1 - h_l - \frac{v}{}$$

NPSHa headloss calculation -headloss from bottom of the tank to entrance of the pump. length is 84inches

$$NPSHa = \frac{P_{atm}}{\gamma} + z_1 - \sum h_L - \frac{P_v}{\gamma}$$

h_L = head loss between free surface and pump inlet

$P_{atm} = 1800 \frac{lb}{ft^2}$, γ @ 50°F = 61.44 $\frac{lbm}{ft^3}$

Find Losses: From there the 5 in nominal diameter is used with the reynolds number (developed in sections 1 and 3 of fluid properties), and using is HLmajor=f*L/D* V^2/2g where HL is the head loss, f is the friction factor (developed from the Haaland equation, see section 7 of fluid properties), L is the length of the pipe, calculated from the dimension diagram above, the pipe diameter developed using matlab coding (see section 1 fluid properties), v is the pipe velocity, given by the equation Q=VA and calculated below and in part 2 of the matlab coding for fluid properties, where Q is the given flow rate, 700 gpm, and A is the Area, developed from the equation A=πr^2, using the diameter calculated above (see part 2 of matlab coding). Our final head loss was 2.86 feet, using $Hl = k(\frac{V^2}{2g})$, where k is the losses from Appendix A Figure 4, V is the fluid velocity from fluid properties section 2, and g is the gravity.

Find losses 5in nominal diameter = 5.047 inside diameter 5.047 in = .4206 ft

Reynolds number = $\frac{\rho V D}{\mu}$

ρ @ 50°F = 62.41 $\frac{lbm}{ft^3}$

$$\frac{62.41(11.22\frac{ft}{s})(.4206 ft)}{8.781\times10^{-4}}$$

Q = VA

$A = \frac{\pi}{4}(.4206 ft)^2 = .1389 ft^2$

700 gpm → cfs = 1.559

$Re = 3.35\times10^5$

$1.559\frac{ft^3}{s} = .1389 ft^2 V$

$V = 11.22\frac{ft}{s}$

using common steel pipe $\epsilon = .00015$

$\frac{\epsilon}{D} = \frac{.00015}{.4206} = 3.57\times10^{-4}$

Using haaland equation $\frac{\epsilon}{D}$ and Reynolds number

$f = .0170$

$h_f = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) = .0172\left(\frac{6 ft}{.4206 ft}\right)\left(\frac{11.22 ft/s}{2(32.2\frac{ft}{s^2})}\right) = .474 ft = 5.68 in$

Tapered reduction (45°)

$K = (.6 + .48f)\left(\frac{D_{lg}}{D_{sm}}\right)^2\left(\left(\frac{D_{lg}}{D_{sm}}\right)^2 - 1\right)\sqrt{\sin\left(\frac{45}{2}\right)}$

$K = (.6 + .48(.0174))\left(\frac{.4206 ft}{.3355 ft}\right)^2\left(\left(\frac{.4206}{.3355}\right)^2 - 1\right)(.6186) = .337$

K_{exit} from tank = .5 (sharp edge)

K_{value} (gate valve) = .13

K_{elbow} (90° Long Radius) = .255 $\Sigma K = 1.2229$

$h_{minor} = \Sigma K\left(\frac{V^2}{2g}\right) = 1.22\left(\frac{11.22\frac{ft}{s}^2}{2(32.2\frac{ft}{s^2})}\right) = 2.39 ft$

$h_{total} = 2.38 ft + .474 ft = \boxed{2.86 ft}$

Finally, using the above equations developed a final NPSH is developed of 32.48 ft. This is less than the calculated necessary NPSH of 20.4, thus our pump is capable.

NPSHa

Free surface is above pump

$$NPSH_a = \frac{P_{atm}}{\gamma} + z_1 - \sum h_L - \frac{P_v}{\gamma}$$

$P_{atm} = 12.5 \frac{lb}{in^2}\left(\frac{144\ in^2}{1\ ft^2}\right) = 1800 \frac{lb}{ft^2}$ P_{vapor} @ $140°F = 2.892 \frac{lb}{in^2} \frac{144\ in^2}{ft^2} = 416.45 \frac{lb}{ft^2}$

z_1 = height of free surface above pump = 14 ft − 14 in = 12.83 ft

pump inlet height

$\sum h_L = 2.86\ ft$

$\gamma @ 140° = 61.44 \frac{lbm}{ft^3}$

$$NPSH_a = \frac{1800 \frac{lb}{ft^2}}{61.44 \frac{lbm}{ft^3}} + 12.83 ft - 2.86 ft - \frac{416.45 \frac{lb}{ft^2}}{61.44 \frac{lbm}{ft^3}}$$

$$= 29.29 ft + 12.83 ft - 2.86 ft - 6.78 ft$$

$$\boxed{NPSH_a = 32.48 ft}$$

Thus, concludes the development of the NPSHA.

Time Development:

Hand calculations developed by Matthew Wright:

The governing equation was Power= Q *ΔP where Q is the given flow rate 700 gpm multiplied by the time. ΔP is the pressure difference developed in the fluid properties to be 113 psi. From there the total time was calculated to be 2.79 hrs.

Matthew Wright

Heating time	Heat Calculations	Ref: Heat and Mass transfer 5th ed	class notes

$P_w = \dot{Q} = \dot{m} c_p \Delta T \qquad \dot{m} = \frac{m}{t} \qquad \dot{Q} = 700\,gpm = 1.559 \frac{ft^3}{s}$

$1\,gpm = .00223 \frac{ft^3}{s}$

$P_w = Q \Delta P \quad \Delta P$ from headloss calc $= 111.191\,psi = 111.199 \frac{lb}{in^2}\left(\frac{144\,in^2}{1\,ft^2}\right) = 16012.66 \frac{lb}{ft^2}$

$1.559 \frac{ft^3}{s}\left(16012.66 \frac{lb}{ft^2}\right) = 24963.74 \frac{ft \cdot lb}{s}$

$\rho_w @ 50^\circ F = 62.4 \frac{lbm}{ft^3}$

$24963.73 \frac{ft \cdot lb}{s} = \frac{3577.4\,lbm\left(1 \frac{Btu}{lbm\,R}\right)(90^\circ R)}{t}$

Volume $= 350\,gal = 46.79\,ft^3$

$+ \frac{\pi}{4}(.1723)^2(14\,ft) + \frac{\pi}{4}(.4206)^2(75.67)$

$\underline{V_{total} = 57.33\,ft^3}$

$24963.73 \frac{ft \cdot lb}{s} = \frac{321966\,Btu}{t}$

$t = \frac{321966\,Btu}{24963.73 \frac{ft \cdot lb}{s}}$

mass $= 62.4 \frac{lbm}{ft^3}(57.33\,ft^3) = \underline{3575.41\,lbm}$

$24963.73 \frac{ft \cdot lb}{s} \frac{1\,Btu}{778.24\,ft \cdot lb} = 32.07 \frac{Btu}{s}$

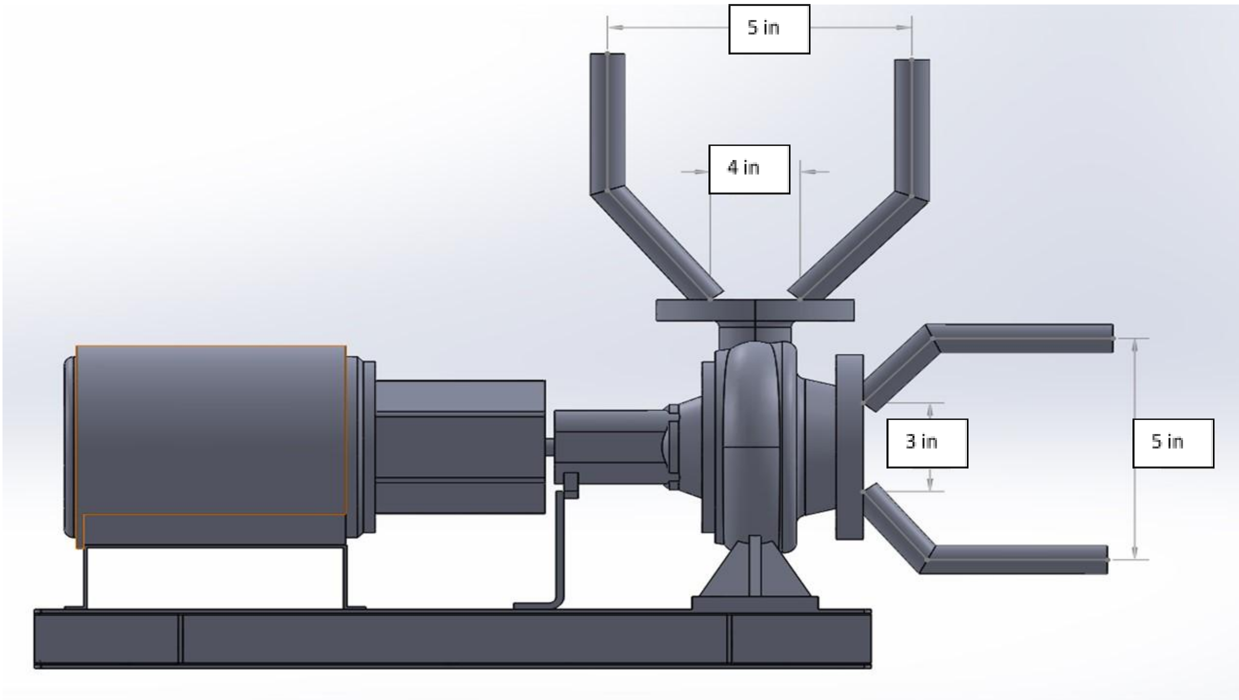
$t = \frac{321966\,Btu}{32.07 \frac{Btu}{s}} = 10039.48\,s$

$t = 167.32\,min = 2.79\,hrs \qquad \boxed{t = 2.79\,hrs}$

time to heat the water

Appendix A figure 1:

This is a side view of the Bell and Gossett pump 1510 3BD (our pump), with the expansion joint required to expand the inlet and outlet heads to proper piping size. Developed in SolidWorks 2018 by Sayler Massey



Appendix A figure 2: Tables: Saturated Water temperature table from Cengel Heat Transfer 7th edition appendix A-4e. Values used were 50 Fahrenheit and 140 Fahrenheit.

TABLE A–4E

Saturated water—Temperature table

		Specific volume, ft³/lbm		Internal energy, Btu/lbm			Enthalpy, Btu/lbm			Entropy, Btu/lbm·R		
Temp., T °F	Sat. press., P_{sat} psia	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
32.018	0.08871	0.01602	3299.9	0.000	1021.0	1021.0	0.000	1075.2	1075.2	0.00000	2.18672	2.1867
35	0.09998	0.01602	2945.7	3.004	1019.0	1022.0	3.004	1073.5	1076.5	0.00609	2.17011	2.1762
40	0.12173	0.01602	2443.6	8.032	1015.6	1023.7	8.032	1070.7	1078.7	0.01620	2.14271	2.1589
45	0.14756	0.01602	2035.8	13.05	1012.2	1025.3	13.05	1067.8	1080.9	0.02620	2.11587	2.1421
50	0.17812	0.01602	1703.1	18.07	1008.9	1026.9	18.07	1065.0	1083.1	0.03609	2.08956	2.1256
55	0.21413	0.01603	1430.4	23.07	1005.5	1028.6	23.07	1062.2	1085.3	0.04586	2.06377	2.1096
60	0.25638	0.01604	1206.1	28.08	1002.1	1030.2	28.08	1059.4	1087.4	0.05554	2.03847	2.0940
65	0.30578	0.01604	1020.8	33.08	998.76	1031.8	33.08	1056.5	1089.6	0.06511	2.01366	2.0788
70	0.36334	0.01605	867.18	38.08	995.39	1033.5	38.08	1053.7	1091.8	0.07459	1.98931	2.0639
75	0.43016	0.01606	739.27	43.07	992.02	1035.1	43.07	1050.9	1093.9	0.08398	1.96541	2.0494
80	0.50745	0.01607	632.41	48.06	988.65	1036.7	48.07	1048.0	1096.1	0.09328	1.94196	2.0352
85	0.59659	0.01609	542.80	53.06	985.28	1038.3	53.06	1045.2	1098.3	0.10248	1.91892	2.0214
90	0.69904	0.01610	467.40	58.05	981.90	1040.0	58.05	1042.4	1100.4	0.11161	1.89630	2.0079
95	0.81643	0.01612	403.74	63.04	978.52	1041.6	63.04	1039.5	1102.6	0.12065	1.87408	1.9947
100	0.95052	0.01613	349.83	68.03	975.14	1043.2	68.03	1036.7	1104.7	0.12961	1.85225	1.9819
110	1.2767	0.01617	264.96	78.01	968.36	1046.4	78.02	1031.0	1109.0	0.14728	1.80970	1.9570
120	1.6951	0.01620	202.94	88.00	961.56	1049.6	88.00	1025.2	1113.2	0.16466	1.76856	1.9332
130	2.2260	0.01625	157.09	97.99	954.73	1052.7	97.99	1019.4	1117.4	0.18174	1.72877	1.9105
140	2.8931	0.01629	122.81	107.98	947.87	1055.9	107.99	1013.6	1121.6	0.19855	1.69024	1.8888
150	3.7234	0.01634	96.929	117.98	940.98	1059.0	117.99	1007.8	1125.7	0.21508	1.65291	1.8680

Appendix A figure 3:

Properties of saturated water taken from Cengel Heat Transfer 7th Appendix 2. Values used were for 50 degrees fahrenheit and 140 fahrenheit.

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APPENDIX 2

TABLE A–9E

Properties of saturated water

Temp. T, °F	Saturation Pressure P_{sat}, psia	Density ρ, lbm/ft³ Liquid	Density Vapor	Enthalpy of Vaporization h_{fg}, Btu/lbm	Specific Heat c_p, Btu/lbm·R Liquid	Specific Heat Vapor	Thermal Conductivity k, Btu/h·ft·R Liquid	Thermal Conductivity Vapor	Dynamic Viscosity μ, lbm/ft·s Liquid	Dynamic Viscosity Vapor	Prandtl Number Pr Liquid	Prandtl Number Vapor	Volume Expansion Coefficient β, 1/R Liquid
32.02	0.0887	62.41	0.00030	1075	1.010	0.446	0.324	0.0099	1.204×10^{-3}	6.194×10^{-6}	13.5	1.00	-0.038×10^{-3}
40	0.1217	62.42	0.00034	1071	1.004	0.447	0.329	0.0100	1.308×10^{-3}	6.278×10^{-6}	11.4	1.01	A0.003 $\times 10^{-3}$
50	0.1780	62.41	0.00059	1065	1.000	0.448	0.335	0.0102	8.781×10^{-4}	6.361×10^{-6}	9.44	1.01	0.047×10^{-3}
60	0.2563	62.36	0.00083	1060	0.999	0.449	0.341	0.0104	7.536×10^{-4}	6.444×10^{-6}	7.95	1.00	0.080×10^{-3}
70	0.3632	62.30	0.00115	1054	0.999	0.450	0.347	0.0106	6.556×10^{-4}	6.556×10^{-6}	6.79	1.00	0.115×10^{-3}
80	0.5073	62.22	0.00158	1048	0.999	0.451	0.352	0.0108	5.764×10^{-4}	6.667×10^{-6}	5.89	1.00	0.145×10^{-3}
90	0.6988	62.12	0.00214	1043	0.999	0.453	0.358	0.0110	5.117×10^{-4}	6.778×10^{-6}	5.14	1.00	0.174×10^{-3}
100	0.9503	62.00	0.00286	1037	0.999	0.454	0.363	0.0112	4.578×10^{-4}	6.889×10^{-6}	4.54	1.01	0.200×10^{-3}
110	1.2763	61.86	0.00377	1031	0.999	0.456	0.367	0.0115	4.128×10^{-4}	7.000×10^{-6}	4.05	1.00	0.224×10^{-3}
120	1.6945	61.71	0.00493	1026	0.999	0.458	0.371	0.0117	3.744×10^{-4}	7.111×10^{-6}	3.63	1.00	0246×10^{-3}
130	2.225	61.55	0.00636	1020	0.999	0.460	0.375	0.0120	3.417×10^{-4}	7.222×10^{-6}	3.28	1.00	0.267×10^{-3}
140	2.892	61.38	0.00814	1014	0.999	0.463	0.378	0.0122	3.136×10^{-4}	7.333×10^{-6}	2.98	1.00	0.287×10^{-3}
150	3.722	61.19	0.0103	1008	1.000	0.465	0.381	0.0125	2.889×10^{-4}	7.472×10^{-6}	2.73	1.00	0.306×10^{-3}

Appendix A figure 4:

Standard K loss factors taken from www.metropumps.com/ResourcesFrictionLossData.pdf.

Friction Losses in Pipe Fittings
Resistance Coefficient K (use in formula $h_f = Kv^2/2g$)

Fitting		LD	½	¾	1	1¼	1½	2	2½-3	4	6	8-10	12-16	18-24
			Nominal Pipe Size (K Value)											
Angle Valve		55	1.48	1.38	1.27	1.21	1.16	1.05	0.99	0.94	0.83	0.77	0.72	0.66
Angle Valve		150	4.05	3.75	3.45	3.30	3.15	2.85	2.70	2.55	2.25	2.10	1.95	1.80
Ball Valve		3	0.08	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04
[illegible]		[illegible]						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gate Valve		8	0.22	0.20	0.18	0.18	0.15	0.15	0.14	0.14	0.12	0.11	0.10	0.10
Globe Valve		340	9.2	8.5	7.8	7.5	7.1	6.5	6.1	5.8	5.1	4.8	4.4	4.1
Plug Valve Branch Flow		90	2.43	2.25	2.07	1.98	1.89	1.71	1.62	1.53	1.35	1.26	1.17	1.08
Plug Valve Straightaway		18	0.48	0.45	0.41	0.40	0.38	0.34	0.32	0.31	0.27	0.25	0.23	0.22
Plug Valve 3-Way Thru-Flow		30	0.81	0.75	0.69	0.66	0.63	0.57	0.54	0.51	0.45	0.42	0.39	0.36
Standard Elbow	90°	30	0.81	0.75	0.69	0.66	0.63	0.57	0.54	0.51	0.45	0.42	0.39	0.36
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	long radius 90°	16	0.43	0.40	0.37	0.35	0.34	0.30	0.29	0.27	0.24	0.22	0.21	0.19
Close Return Bend		50	1.35	1.25	1.15	1.10	1.05	0.95	0.90	0.85	0.75	0.70	0.65	0.60
Standard Tee	Thru-Flow	20	0.54	0.50	0.46	0.44	0.42	0.38	0.36	0.34	0.30	0.28	0.26	0.24
	Thru-	60	1.62	1.50	1.38	1.32	1.26	1.14	1.08	1.02	0.90	0.84	0.78	0.72
90 Bends, Pipe Bends, Flanged Elbows, Butt-Welded Elbows	r/d=1	20	0.54	0.50	0.46	0.44	0.42	0.38	0.36	0.34	0.30	0.28	0.26	0.24
	r/d=2	12	0.32	0.30	0.28	0.26	0.25	0.23	0.22	0.20	0.18	0.17	0.16	0.14
	r/d=3	12	0.32	0.30	0.28	0.26	0.25	0.23	0.22	0.20	0.18	0.17	0.16	0.14
	r/d=4	14	0.38	0.35	0.32	0.31	0.29	0.27	0.25	0.24	0.21	0.20	0.18	0.17
	r/d=6	17	0.46	0.43	0.39	0.37	0.36	0.32	0.31	0.29	0.26	0.24	0.22	0.20
	r/d=8	24	0.65	0.60	0.55	0.53	0.50	0.46	0.43	0.41	0.36	0.34	0.31	0.29
	r/d=10	30	0.81	0.75	0.69	0.66	0.63	0.57	0.54	0.51	0.45	0.42	0.39	0.36
	r/d=12	34	0.92	0.85	0.78	0.75	0.71	0.65	0.61	0.58	0.51	0.48	0.44	0.41
	r/d=14	38	1.03	0.95	0.87	0.84	0.80	0.72	0.68	0.65	0.57	0.53	0.49	0.46
	r/d=16	42	1.13	1.05	0.97	0.92	0.88	0.80	0.76	0.71	0.63	0.59	0.55	0.50
	r/d=18	45	1.24	1.15	1.06	1.01	0.97	0.87	0.83	0.78	0.69	0.64	0.60	0.55

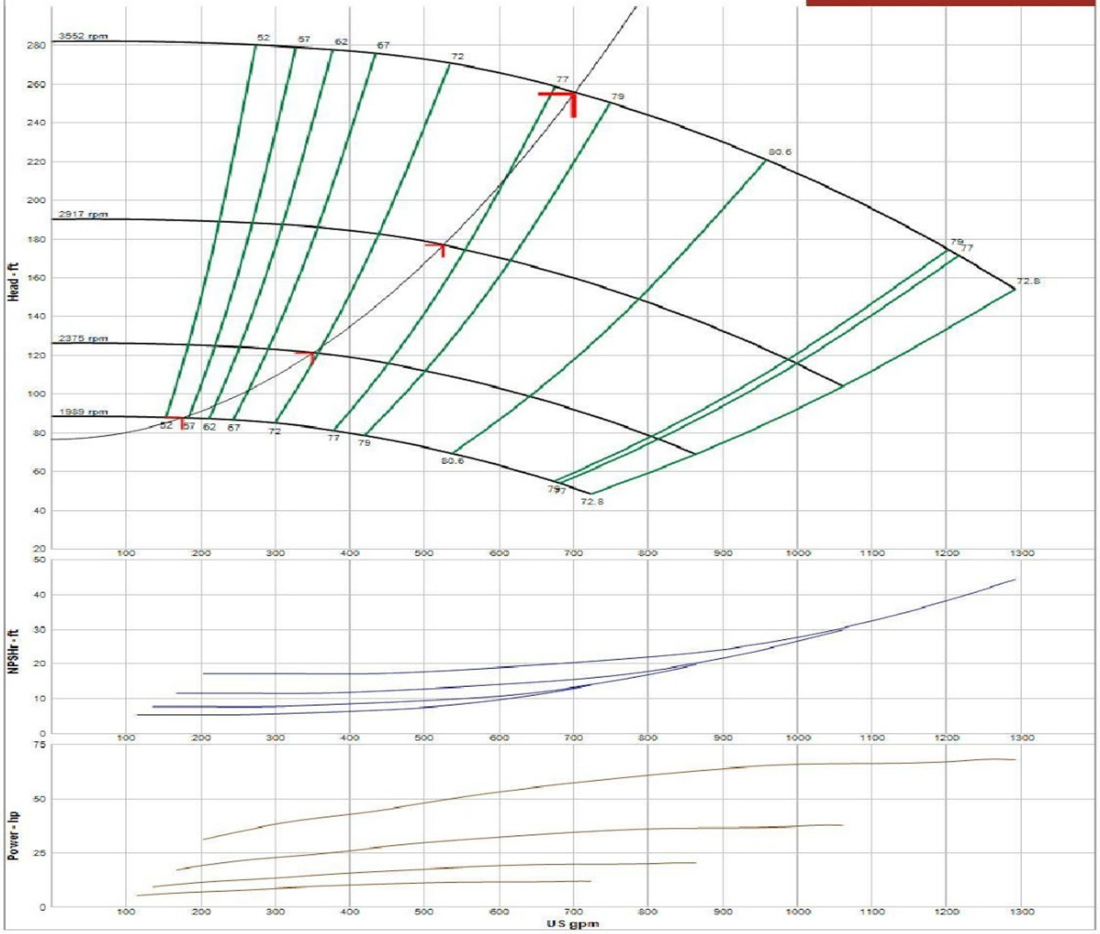
Appendix A Figure 5:

Pump efficiency curve:

Bell & Gossett
a xylem brand

Performance Curve

e-1510
3BD



Pump Selection Summary

Pump Capacity	700 US gpm	RPM @ Duty Point	3552
Pump Head	255 ft	Impleller Diameter	8.25 in
Control Head	76.5 ft	NPSHr	20.4
Duty Point Pump Efficiency	77.7 %	Motor HP	75
Pump PLEVv Efficiency	70.5 %	Motor Speed	3600 rpm
Duty point Power	57.4 bhp	Minimum Shutoff Head	282 ft
Minimum Flow at RPM	220 gpm	Fluid Type	Water
Flow @ BEP	959 gpm	Fluid Temperature	140 °F
Weight (approx. - consult rep)	1207 lbs	Floor Space	6.98 ft²

xylem
Let's Solve Water

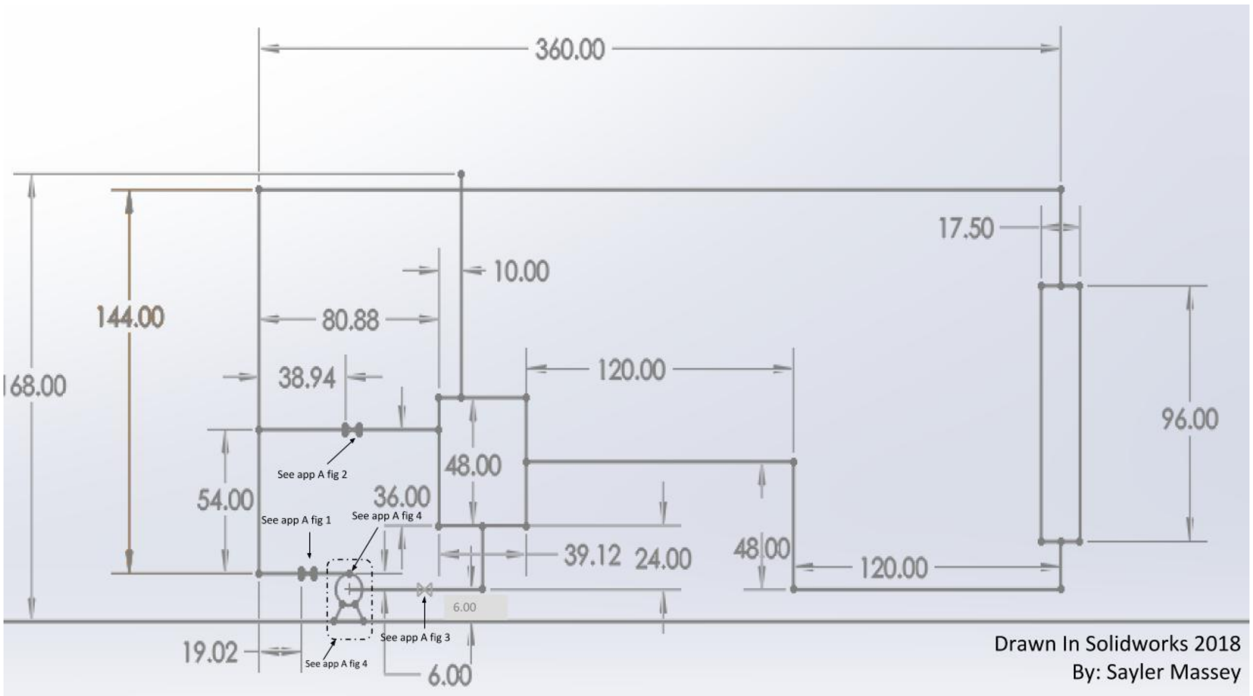
Xylem Inc.
8200 N. Austin Avenue, Morton Grove, IL 60053
Phone: (847)966-3700 Fax: (847)965-8379
www.bellgossett.com

Appendix B: Gate and Check Valve Information:

The gate valve used was a 3” Pressure class 200 valve from McMaster-Carr with an expansion joint to move back to 5”. More information can be found at https://www.mcmaster.com/4857k19

The check valve used was a 3” check valve, more can be found at https://www.mcmaster.com/4616k98

Appendix C: Full copies of All calculations attached as appendices:



```
%Shishir Khanal
%ME 4465; Project - 2
%Group Partners:
%      Sayler Massey
%      Matthew Wright
% Purpose of the code:
%    Part-I: Determine minimum Diameter
%    Part - II: Calculate the Actual Velocity
%    Part-III: Calculate Reynolds Number
%    Part-IV: Friction Factor calculation
%    Part V: Minor Loss Calculation
%    Part VI:Calculate the friction loss
%    Part VII:Haaland and minorloss functions
%    Part VIII:Calculation of total Reduction loss due to Pump
%-----------------------------------------------------------
clear;
clc;
%clears the worksheet and command screen

%-----------------------------------------------------------
%Part-I: Determine minimum Diameter
FlowRate = 1.559;
% Q = 700 gpm ; 1 gpm = .00223 ft^3/s
vel = 15;
% Optimum velocity used
PipeDia = sqrt((4*FlowRate)/(vel*pi));
% this is the minimum size pipe that meets the requirements
PipeDiaAvailable = 0.4206;
% this is the inner diameteravailable sch 40 size pipe
% 0.4167 is the nominal diameter of pipe used
%----------------------------------------------------------

%Part-II: Calculate the Actual Velocity

 velActual = FlowRate/((pi/4)*PipeDiaAvailable^2);
%Actual velocity calculated using the new diameter with same flow rate
% v=Q/A; A = (Pi/4)*D^2
%-----------------------------------------------------------
%Part-III: Calculate Reynolds Number
Density50F = 62.47;
%Density of water at 50F(lbm/ft^3)
%this was chosen considering the maximum density at 50F (50F-140F)range
CoefDynaVisc = 8.791*10^-4;
%(lbm/(ft*s))
ReynoldNum = Density50F*velActual*PipeDiaAvailable/CoefDynaVisc ;
%Unitless
%------------------------------------------------------------
% Part-IV: Calculate Friction factor

 epsilon = 0.00015;
%Chosing material to be Common Steel(e=0.00015 ft)
FrictionFactor = Haaland(epsilon,PipeDiaAvailable,ReynoldNum);
%Friction factor calculation through the function
%---------------------------------------------------------------

% Part - V: Minor Loss Calculation
```

```
% Coefficients for minor loss Vaiues for
% 90 deg elbows (long Radius) = .34(*7)
% Gate Valve(Swing) = .13
% Check Valve = .825
% Screwed Fittings = .72
% Entry loss(Sharp Edged) = 0.5(*3)
% Exit loss(Sharp Edged) = 1(*3)
% T-joint = .32
kSum = .72+.825+(7*.34)+.13+(3*0.5)+1*3+KredExp(FrictionFactor)+.32;
%sum the minor loss coeficients
LossMinor = minorloss(kSum, vel);
%Calculate the minor loss from the minorloss function

%---------------------------------------------------------

%Part-VI: Calculate the Headloss loss
Length = 83.67;
g=32.2;
FrictionLoss = ((FrictionFactor*Length*(vel)^2)/(.4206*2*g));
%Friction loss for the length of the pipe except
HeadlossSection = 230.73;
% Head loss due to the pressure change i the 8 ft section
ElevationDiff = 0.5;
%change in elevation of the inlet and outlet of the pump
HeadlossTotal = FrictionLoss+ LossMinor+HeadlossSection+ElevationDiff;
%Frictionloss throughout the length of the pipe
%Minor losses due to fittings
%---------------------------------------------------------

%Part VII: Haaland and minorloss functions
function FrictionFactor = Haaland(epsilon,PipeDia,ReynoldNum)
%Haaland Equation to calculate the friction factor
 %   Haaland equation to calculate the friction factor
% Input Variables = Reynolds Number, Epsilon = Relative Roughness of the
%                  pipe surface and the Diameter of the pipe
% Output Value = friction factor
term1 =((epsilon/PipeDia)/3.7)^1.11;
term2 = (6.9/ReynoldNum);
FrictionFactor = 1/(-1.8*log10(term1+term2))^2;

end

function MLoss = minorloss(flowCoeff, velocity )
%UNTITLED Summary of this function goes here
%   Calculates the minor loss
% units in British Units
acelgr = 32.2 ;
MLoss = (flowCoeff*(velocity)^2)/(2*acelgr);
end

%------------------------------------------------------------
% Part VIII: Calculation of total Reduction loss due to Pump

function RedExp = KredExp(frictionfactor)
%UNTITLED Summary of this function goes here
```

```matlab
%   Calculates the reduction and expansion losses
% units in British Units
D1Red = 5.046;
D2Red = 4.026;
D1Exp = 3.068;
D2Exp = 5.046;
Kred = (0.6+0.48*frictionfactor)*(D1Red/D2Red)^2*(((D1Red/D2Red)^2)-
1)*sqrt(sin(pi/8));
Kexp = (1+(0.8*frictionfactor))*(1-(D1Exp/D2Exp)^2)^2;
RedExp = Kred + Kexp;

end
```

Workspace

Name	Value
CoefDynaVisc	8.7910e-04
Density50F	62.4700
ElevationDiff	0.5000
epsilon	1.5000e-04
FlowRate	1.5590
FrictionFactor	0.0170
FrictionLoss	11.8412
g	32.2000
HeadlossSection	230.7300
HeadlossTotal	276.6645
kSum	9.6151
Length	83.6700
LossMinor	33.5933
PipeDia	0.3638
PipeDiaAvailable	0.4206
ReynoldNum	3.3537e+05
vel	15
velActual	11.2206

Shishir Kharel | Hand Calcs ME 4405 | Group Members: Sagler Massey, Matthew Wright | 1

→ Minor Loss Calculation

K_m for Globe valve = 7.1

K_m for Gate Valve (Swing type) = .13

Other fittings chosen based on the requirement of change in direction of pipe.

Hence, Gate valve is used for the purpose

$\Sigma K = 9.6151$

h_m = minorloss (9.6151, 11.22) = 18.7927 ft

* Head Loss Calculation

$h_f = f \frac{L}{D} \frac{v^2}{2g} = 11.8412 ft$

length of pipe = 83.67 ft
$g = 32.2 fts^{-2}$
$v = 11.22 fts^{-1}$
$D = 0.81206$ ft

$z_2 - z_1 = 0.5 ft$

h_L due to section $= \frac{\Delta P}{\gamma}$

$= \frac{100 \, lbf \, in^{-2}}{62.41 lbf \, ft^{-3}} \times \frac{144 \, in^2}{1 \, ft^2}$

$\therefore h_{L_{sec}} = 230.73 ft$

Modified Bernoulli's,

$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + h_f + h_m$

$\frac{P_1 - P_2}{\rho g} = z_2 - z_1 + h_f + h_m$

$\therefore$ For system $h_L = 0.5 ft + 11.8412 ft + 18.7927 ft = 31.14 ft$

Also, the section has a significant head loss.

So, $h_{L_{Total}} = h_{L_{sec}} + h_{L_{syst}} = 230.73 ft + 31.14 ft = 261.87 ft$

$h_{L_{Total}} = \frac{\Delta P}{\gamma}$

$\therefore \Delta P = 261.87 ft \times 62.41 \, lbf \, ft^{-3} \times \frac{1 ft^2}{144 in^2} = 113.5 psi$

* Flow Rate,

$$Q = vA$$

$$1.559\,ft^3s^{-1} = 15\,ft\,s^{-1} \times \frac{\pi}{4} \times D^2$$

$$\therefore D = \sqrt{\frac{4 \times 1.559}{15\pi}} = 0.3638\,ft$$

The schedule 40 pipe that will not exceed the velocity will have the diameter just greater than D.

$$\therefore D = 0.4206\,ft \text{ (i.e. } 5.047\,in)$$

Now,

Calculating the actual velocity

$$Q = vA$$

$$1.559\,ft^3s^{-1} = v \times \frac{\pi}{4} \times (0.4206\,ft)^2$$

$$\therefore v = 11.2206\,ft\,s^{-1}$$

* Reynold's number

$$Re^{\#} = \frac{\rho v D}{\mu}$$

$$\therefore Re^{\#} = 3.354 \times 10^5$$

$\rho_{w_{50°F}} = 62.47\,lbm\,ft^{-3}$

$v = 11.2206\,ft\,s^{-1}$

$D = 0.4206\,ft$

$\mu = 2.730 \times 10^{-5}\,\cancel{lbf}\,s\,ft^{-2} \times \frac{32.2\,lbm\,ft\,s^{-2}}{\cancel{1\,lbf}}$

$\therefore \mu = 8.791 \times 10^{-4}\,lbm\,ft^{-1}s^{-1}$

* Friction factor

* New Riveted steel ($\epsilon = 0.01\,ft$) [Source: Notes]

Haaland (0.01 ft, 0.4206 ft , 3.354×10^5) => 0.0522

* New Common steel ($\epsilon = 0.00015\,ft$) [Source Notes]

Haaland (0.00015 ft, 0.4206 ft, 3.354×10^5) => 0.0170

* We do not need an expensive pipe with very low surface roughness. So the New common steel is good enough to meet the purpose. We selected steel from steel & iron who had the same 'ε' because ~~of~~ of it's strength.

NPSHa headloss calculation - headloss from bottom of the tank to entrance of the pump. length is 84 inches

$NPSHa = \frac{P_{atm}}{\gamma} + z_1 - \Sigma h_L - \frac{P_v}{\gamma}$ h_L = head loss between free surface and pump inlet

$P_{atm} = 1800 \frac{lb}{ft^2}$, $\gamma @ 50°F = 61.44 \frac{lbm}{ft^3}$

Find losses 5in nominal diameter = 5.047 in inside diameter 5.047 in = .4206 ft

Reynolds number = $\frac{\rho V D}{\nu}$ $\rho @ 50°F = 62.41 \frac{lbm}{ft^3}$

$\frac{62.41(11.22 \frac{ft}{s})(.4206 ft)}{8.781 \times 10^{-4}}$

$Q = VA$

$A = \frac{\pi}{4}(.4206 ft)^2 = .1389 ft^2$

$Re = 3.35 \times 10^5$

700 gpm → cfs = 1.559

$1.559 \frac{ft^3}{s} = .1389 ft^2 V$

using common steel pipe $\epsilon = .00015$

$V = 11.22 \frac{ft}{s}$

$\frac{\epsilon}{D} = \frac{.00015}{.4206} = 3.57 \times 10^{-4}$

Using haaland equation $\frac{\epsilon}{D}$ and Reynolds number

$f = .0170$

$h_f = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) = .017\left(\frac{6 ft}{.4206 ft}\right)\left(\frac{11.22 ft/s}{2(32.2 \frac{ft}{s^2})}\right) = .474 ft = 5.68 in$

Tapered reduction (45°)

$K = (.6 + .48f)\left(\frac{D_{lg}}{D_{sm}}\right)^2\left(\left(\frac{D_{lg}}{D_{sm}}\right)^2 - 1\right)\sqrt{\sin\left(\frac{45}{2}\right)}$

$K = (.6 + .48(.0174))\left(\frac{.4206 ft}{.3355 ft}\right)^2\left(\left(\frac{.4206}{.3355}\right)^2 - 1\right)(.6186) = .337$

K_{exit} from tank = .5 (sharp edge)

K_{valve} (gate valve) = .13

K_{elbow} (90° Long Radius) = .255 $\Sigma K = 1.2229$

$h_{minor} = \Sigma K\left(\frac{V^2}{2g}\right) = 1.22\left(\frac{11.22 \frac{ft}{s}^2}{2(32.2 \frac{ft}{s^2})}\right) = 2.39 ft$

$h_{total} = 2.38 ft + .474 ft = \boxed{2.86 ft}$

Matthew Wright	Hand calc for NPSHa	Team Members Saylor Massey Shishir Khanal	2/2

NPSHa

Free surface is above pump

$$NPSH_a = \frac{P_{atm}}{\gamma} + z_1 - \sum h_L - \frac{P_v}{\gamma}$$

$P_{atm} = 12.5 \frac{lb}{in^2}\left(\frac{144\ in^2}{1\ ft^2}\right) = 1800 \frac{lb}{ft^2}$ P_{vapor} @ $140°F = 2.892 \frac{lb}{in^2} \frac{144\ in^2}{} = 416.45 \frac{lb}{ft^2}$

z_1 = height of free surface above pump = 14ft - 14in = 12.83 ft
pump inlet height

$\sum h_L = 2.86$ ft

γ @ $140° = 61.44 \frac{lbm}{ft^3}$

$$NPSH_a = \frac{1800 \frac{lb}{ft^2}}{61.44 \frac{lbm}{ft^3}} + 12.83ft - 2.86ft - \frac{416.45 \frac{lb}{ft^2}}{61.44 \frac{lbm}{ft^3}}$$

$= 29.29ft + 12.83ft - 2.86ft - 6.78ft$

$$\boxed{NPSH_a = 32.48ft}$$

Matthew Wright

Heating time	Heat Calculations	Ref: Heat and Mass transfer 5th ed	class notes

$P_w = \dot{Q} = \dot{m} c_p \Delta T$ $\quad \dot{m} = \frac{m}{t}$ $\quad \dot{Q} = 700\,gpm = 1.559 \frac{ft^3}{s}$

$1\,gpm = .00223 \frac{ft^3}{s}$

$P_w = Q \Delta P$ $\quad \Delta P$ from headloss calc $= 111.191\,psi \approx 111.199 \frac{lb}{in^2}\left(\frac{144\,in^2}{1\,ft^2}\right) = 16012.66 \frac{lb}{ft^2}$

$1.559 \frac{ft^3}{s}\left(16012.66 \frac{lb}{ft^2}\right) = 24963.74 \frac{ft \cdot lb}{s}$

$\rho_w @ 50^\circ F = 62.4 \frac{lbm}{ft^3}$

$24963.73 \frac{ft \cdot lb}{s} = \frac{3577.4\,lbm}{t}\left(1 \frac{Btu}{lbm\,R}\right)(90^\circ R)$

Volume $= 350\,gal = 46.79\,ft^3$

$+ \frac{\pi}{4}(.1723)^2(14\,ft) + \frac{\pi}{4}(.4206)^2(75.67)$

$V_{total} = 57.33\,ft^3$

$24963.73 \frac{ft \cdot lb}{s} = \frac{321966\,Btu}{t}$

mass $= 62.4 \frac{lbm}{ft^3}(57.33\,ft^3) = 3575.4\,lbm$

$t = \frac{321966\,Btu}{24963.73 \frac{ft \cdot lb}{s}}$

$24963.73 \frac{ft \cdot lb}{s} \frac{1\,Btu}{778.2\,ft \cdot lb} = 32.07 \frac{Btu}{s}$

$t = \frac{321966\,Btu}{32.07 \frac{Btu}{s}} = 10039.48\,s$

$t = 167.32\,min = 2.79\,hrs$ $\quad \boxed{t = 2.79\,hrs}$

time to heat the water

Scanned by CamScanner

Textbook References

Munson, Bruce Roy, et al. Fundamentals of Fluid Mechanics. John Wiley & Sons, Inc., 2013. pg. 439 - Elbows and Valves, pg. 434, 436 - Entrance and Exit Losses, pg. 739 Table B.1 - Water Properties

Cengel. Heat and Mass Transfer. 2015. 5th edition

Pump References

Losses from reduction

https://neutrium.net/fluid_flow/pressure-loss-from-fittings-expansion-and-reduction-in-pipe-size/

minor loss chart

http://www.metropumps.com/ResourcesFrictionLossData.pdf

Entry exit losses

-Fundamentals of fluid mechanics 7th Ed. Munson

Head loss to pressure drop

https://www.engineeringtoolbox.com/pump-head-pressure-d_663.html

Pump information

http://documentlibrary.xylemappliedwater.com/wp-content/blogs.dir/22/files/2014/01/B-261G-e-1510-Curves.pdf

3BD Constant speed

https://esp-systemwize.com/pumps/details;catalogs=%5B898%5D;fluid_state_id=6254441;list_state_id=3835146;clsi=3835146;dp=%7B%22flow%22:%7B%22value%22:700,%22unit%22:%22USGPM%22%7D,%22head%22:%7B%22value%22:255,%22unit%22:%22FT_FLUID%22%7D,%22staticHead%22:%7B%22value%22:76.5,%22unit%22:%22FT_FLUID%22%7D,%22load%22:1,%22overspeed%22:%22Off%22,%22operatingPointHead%22:%22systemCurve_speedAdjustCalc%22,%22plevMode%22:%22MODE_THREE_HYDRAULIC%22,%22pumpCount%22:1,%22pumpDesignStrategy%22:%22PARALLEL%22%7D;pump_state_id=50672638;wp_id=113446;current_catalog=898;sts=1;co=1

4BD Variable Speed

https://esp-systemwize.com/pumps/details;catalogs=%5B898%5D;fluid_state_id=6254441;list_state_id=3835146;clsi=3835146;dp=%7B%22flow%22:%7B%22value%22:700,%22unit%22:%22USGPM%22%7D,%22head%22:%7B%22value%22:255,%22unit%22:%22FT_FLUID%22%7D,%22staticHead%22:%7B%22val

ue%22:76.5,%22unit%22:%22FT_FLUID%22%7D,%22load%22:1,%22overspeed%22:%22Off%22,%22operatingPointHead%22:%22systemCurve_speedAdjustCalc%22,%22plevMode%22:%22MODE_THREE_HYDRAULIC%22,%22pumpCount%22:1,%22pumpDesignStrategy%22:%22PARALLEL%22%7D;pump_state_id=50672641;wp_id=113446;current_catalog=898;sts=1;co=1

4EB constant speed

https://esp-systemwize.com/pumps/details;catalogs=%5B898%5D;fluid_state_id=6254441;list_state_id=3835150;clsi=3835150;dp=%7B%22flow%22:%7B%22value%22:700,%22unit%22:%22USGPM%22%7D,%22head%22:%7B%22value%22:255,%22unit%22:%22FT_FLUID%22%7D,%22staticHead%22:%7B%22value%22:0,%22unit%22:%22FT_FLUID%22%7D,%22load%22:1,%22overspeed%22:%22Off%22,%22operatingPointHead%22:%22systemCurve_speedAdjustCalc%22,%22plevMode%22:%22MODE_THREE_HYDRAULIC%22,%22pumpCount%22:1,%22pumpDesignStrategy%22:%22PARALLEL%22%7D;pump_state_id=50672674;wp_id=113446;current_catalog=898;sts=2;co=1

3EB variable speed

https://esp-systemwize.com/pumps/details;catalogs=%5B898%5D;fluid_state_id=6254441;list_state_id=3835151;clsi=3835151;dp=%7B%22flow%22:%7B%22value%22:700,%22unit%22:%22USGPM%22%7D,%22head%22:%7B%22value%22:255,%22unit%22:%22FT_FLUID%22%7D,%22staticHead%22:%7B%22value%22:76.5,%22unit%22:%22FT_FLUID%22%7D,%22load%22:1,%22overspeed%22:%22Off%22,%22operatingPointHead%22:%22systemCurve_speedAdjustCalc%22,%22plevMode%22:%22MODE_THREE_HYDRAULIC%22,%22pumpCount%22:1,%22pumpDesignStrategy%22:%22PARALLEL%22%7D;pump_state_id=50672676;wp_id=113446;current_catalog=898;sts=1;co=1