Design of a Cost Efficient Pumping System

Fluid Mechanics - Team 8

MECH 3314

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Introduction

For this project, the task was to optimize an El Paso, Tx water supply system that uses a gravity driven flow from five large storage tanks and currently runs at 65% efficiency. This could be achieved by adding a set of pumps, changing pipeline diameter for a water line, or reducing the number of hours of operation. However, the system must run between the hours of 10pm-6am (coldest hour of the day) at an electricity rate of 0.087 $/kW-hr. The desired output should be a more efficient and cost-friendly system all to be determined within a span of 5 years. As engineers, it is desired to have the most efficient system in place but unfortunately may come at a great cost. Therefore, this project showcases a common real-world engineering problem where one searches for a balance between cost and efficiency of a water system.

Theoretical Background

When deciding which route to go about this project, it was first decided to calculate the overall cost for the original piping system provided operated by a single pump. In order to choose a pump from appendix 4 the total head loss needed to be calculated as well as a flowrate of 625 gal/min was calculated with an assumption of 8 hours of operation. However, when total head loss was calculated the value exceeded the pump options in the graph. Thus, it was concluded that modifications were necessary to the system for there was not even a current price option. When calculating total head loss for the pump ,as seen in the head loss equation in appendix 5, pressure, velocity out, and z1 can all be neglected. Thus, in order to calculate the total head loss only minor and major losses due to friction in piping as well as height of the tank are the only values needed for consideration. It was also important to notice how many valves and elbows the current design contained for minor head losses. The head loss was one of the most crucial values in deciding the new system, since the range was what indicated pump selection. Head loss can be summarized as the power lost from the work being done by the pump as well as the additional power the pump will have to perform to meet the requirements needed throughout the system where the water flows. In order to change these losses, one needs to analyze the size of a water pipe. If the pipe is too small it will cause pipe friction; the rate at which the water is flowing. For instance if a pipeline is too small, the water will flow faster in the center and will be slower along the “walls” of the inside of the pipe. Now, if the pipeline is larger, it will flow at a more even rate and cause less damage to the pipe depending on the material used.

The best bet for going about this project was to first determine the pipe size along with the corresponding flow rate according to the pipe size. Next was the number of pump selection, in this case, 3 pumps provided the most efficient results, as well as met the criteria of maintaining mandated operations. It is understood that when choosing a pump if the price is lower, the pump may not run at a high efficiency, which is why engineers were called in. From the given scenario, it was noticed that the head was too high for the system to work.

In order to get the total cost of the new system it was key to calculate various factors. First assumption being the temperature within the allotted time. **70 F** was the chosen temperature, and that was within the duration of **3.2 hours**. With that information we were able to get a flow rate of **625** to fill the tank requirement. The material that was decided to be used was cast iron. After some calculations and assumptions, it was decided to use 3 pumps due to the efficiency being at a great percentage as well as meeting criteria needed and at a reasonable price.

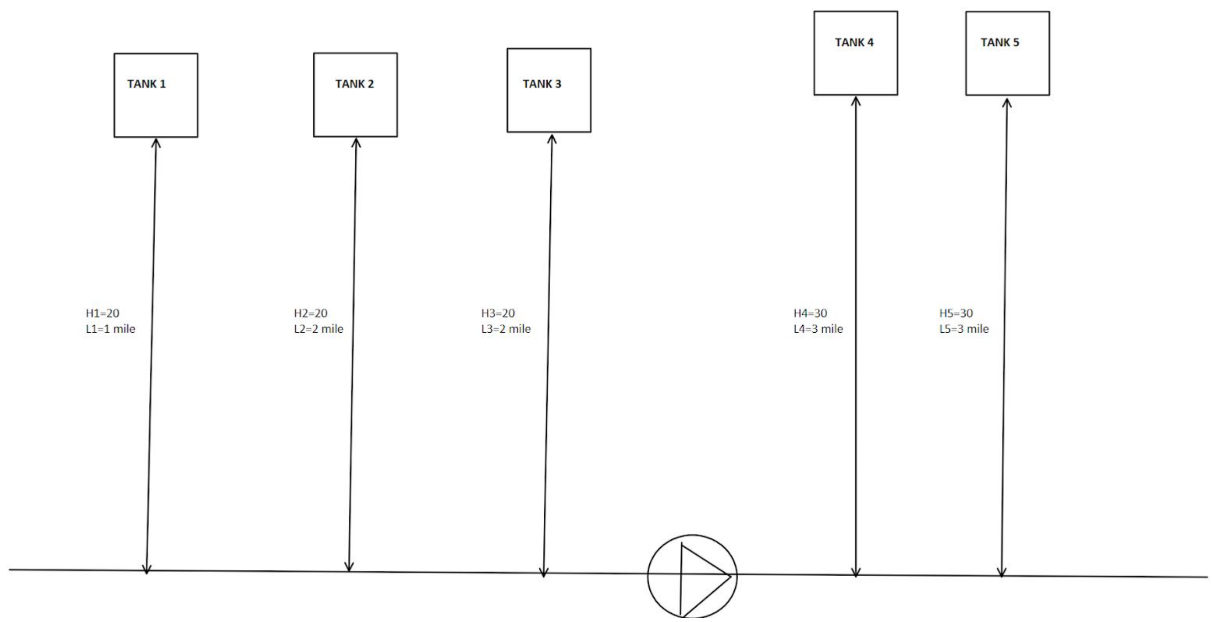
Results

The final pump system is as follows the sketch in appendix 2. For the recommendation, 3 pumps are used in this system; pump 1 is for tank 1 and 4, pump 2 is for tank 2 and 5, and pump 3 is for tank 3. The pipeline and pump for tank 3 is left alone from the original design for this line had a sufficient head loss to correspond to a pump without changing pipeline diameter. However, pump 1 and 2 were modified to have a pipe diameter of 10.4 in running to their corresponding lines. This leads to each pump needing to fill two tanks or one tank in the case of pump 3. Instead of filling 300,000 gallons, pump 1 and 2 need to fill 120,000 gallons each and pump 3 needs to fill 60,000 gallons, thus at the current flow rate each pump would fill their tanks concurrently at 1.6hr/tank. This shortened time reduces the total cost of the electricity required to operate the system to $10.38 per night, the total cost per year is $3788.72, and the total cost per 5 years is $18943.6. Not included in the cost just mentioned is installation cost of the new piping, pump, motor, elbows, and valves. The total installation cost is $90,912; this is a flat rate initial cost. The total cost of electricity and including the installation cost for 5 years is $109,855.6.

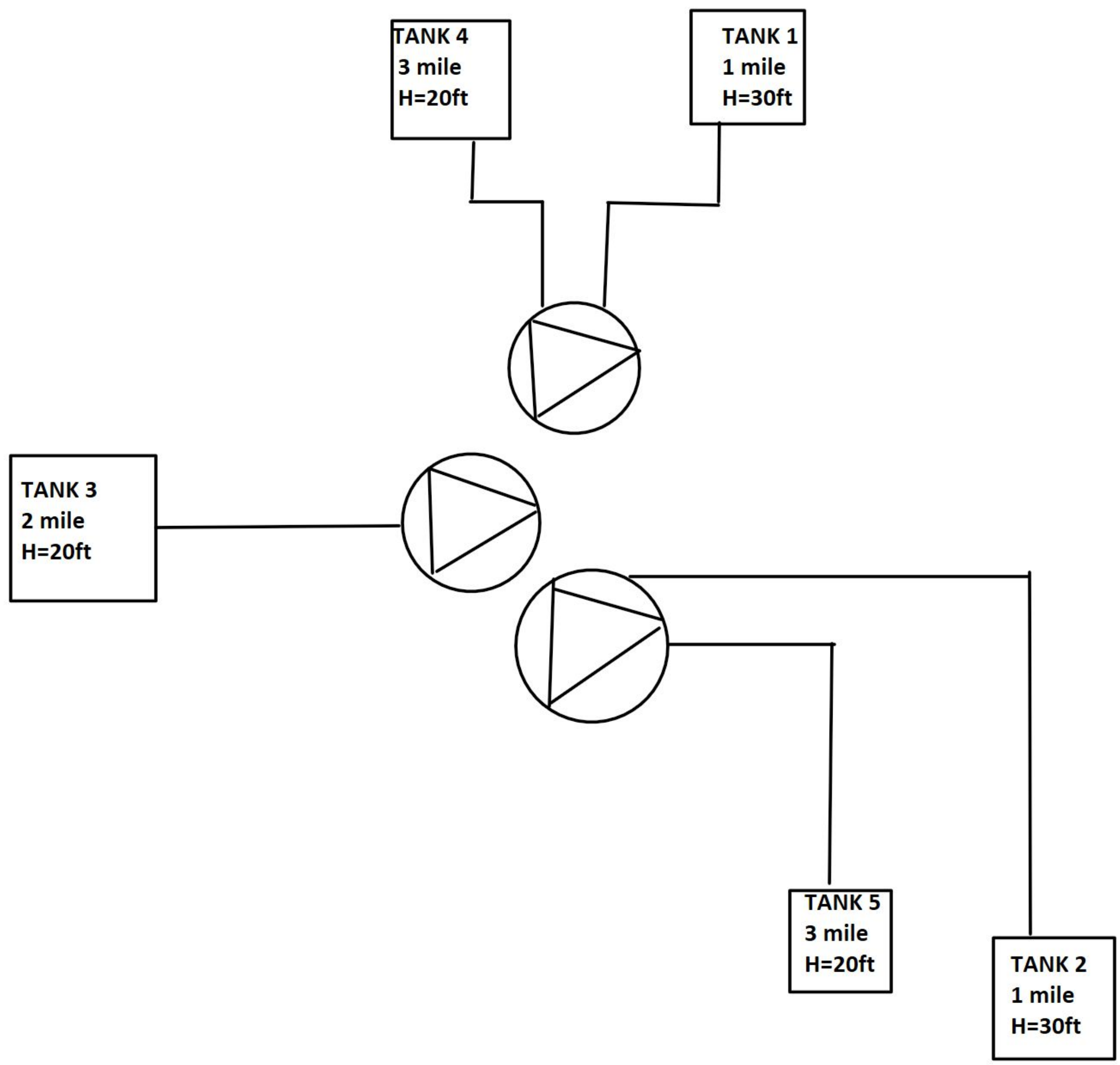
Pump #	Tanks	Volume	HL	Power	Daily hours	Efficiency	Prices	
Pump 1	1,4	120000	108.2	15.65 KW/h	3.2	81%	Install	$90,912
Pump 2	2,5	120000	108.2	15.65 KW/h	3.2	81%	5 Years	$18,943.60
Pump 3	3	60000	79.08	11.93 KW/h	1.6	65%	Net	$109,855.60

Appendix

Appendix 1: Original Design Sketch



Appendix 2: Recommendation Design Sketch



Appendix 3: Excel calculations

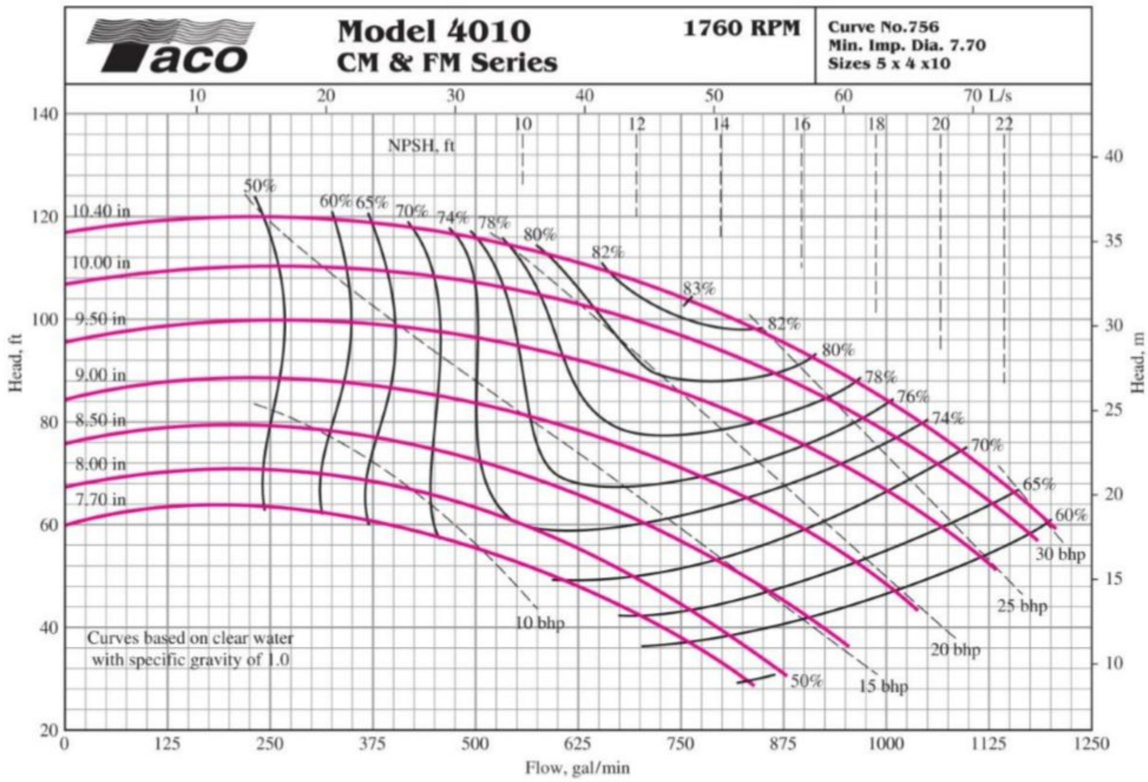
Current System

Current System									
Tanks			**Volume**			**Flow**			
Number	Assumptions		Flowrate (GPM)	Flowrate (ft^3/s)	Velocity (ft/s)	Re	Friction Factor	KL	**Head Losses (ft)**
	Elbows	53						Elbow	
	Valves	4						47.7	
1	Temperature (F)	70						Valves	
	Diameter (ft)	0.75						2.52	
	delta z (ft)	20						Total	
	Lenght (ft)	5280	625	1.392510417	3.151998807	224644.8204	0.02024721688	50.22	49.73747266
	Elbows	53						Elbow	
	Valves	4						47.7	
2	Temperature (F)	70						Valves	
	Diameter (ft)	0.75						2.52	
	delta z (ft)	20						Total	
	Lenght (ft)	5280	625	1.392510417	3.151998807	224644.8204	0.02024721688	50.22	49.73747266
	Elbows	106						Elbow	
	Valves	4						95.4	
3	Temperature (F)	70						Valves	
	Diameter (ft)	0.75						2.52	
	delta z (ft)	20						Total	
	Lenght (ft)	10560	625	1.392510417	3.151998807	224644.8204	0.02024721688	97.92	79.08580587
	Elbows	159						Elbow	
	Valves	4						143.1	
4	Temperature (F)	70						Valves	
	Diameter (ft)	0.75						2.52	
	delta z (ft)	30						Total	
	Lenght (ft)	15840	625	1.392510417	3.151998807	224644.8204	0.02024721688	145.62	118.4343277
	Elbows	159						Elbow	
	Valves	4						143.1	
5	Temperature (F)	70						Valve	
	Diameter (ft)	0.75						2.52	
	delta z (ft)	30						Total	
	Lenght (ft)	15840	625	1.392510417	3.151998807	224644.8204	0.02024721688	145.62	118.4343277
Results									
Total head Loss	415.4294066	Efficiency	65%	Power consumpted	65 kW/hr	Total cost for 5 years	N/A	Hours of operation	8

Recommended System

Recommended System									
Tanks			**Volume**			**Flow**			**Head Losses (ft)**
Number	Assumptions		Flowrate (GPM)	Flowrate (ft^3/s)	Velocity (ft/s)	Re	Friction Factor	KL	
	Elbows	53						Elbow	
	Valves	4						47.7	
1	Temperature (F)	70						Valves	
	Diameter (ft)	0.8666						2.52	
	delta z (ft)	30						Total	
	Lenght (ft)	5280	625	1.392510417	3.151998807	194553.8283	0.01953973551	50.22	44.69787175
	Elbows	53						Elbow	
	Valves	4						47.7	
2	Temperature (F)	70						Valves	
	Diameter (ft)	0.8666						2.52	
	delta z (ft)	30						Total	
	Lenght (ft)	5280	625	1.392510417	3.151998807	194553.8283	0.01953973551	50.22	44.69787175
	Elbows	106						Elbow	
	Valves	4						95.4	
3	Temperature (F)	70						Valves	
	Diameter (ft)	0.75						2.52	
	delta z (ft)	20						Total	
	Lenght (ft)	10560	625	1.392510417	3.151998807	224644.8204	0.02024721688	97.92	79.08580587
	Elbows	159						Elbow	
	Valves	4						143.1	
4	Temperature (F)	70						Valves	
	Diameter (ft)	0.8666						2.52	
	delta z (ft)	20						Total	
	Lenght (ft)	15840	625	1.392510417	3.151998807	194419.1268	0.01953973551	145.62	63.51400948
	Elbows	159						Elbow	
	Valves	4						143.1	
5	Temperature (F)	70						Valve	
	Diameter (ft)	0.75						2.52	
	delta z (ft)	30						Total	
	Lenght (ft)	15840	625	1.392510417	3.151998807	194419.1268	0.01953973551	145.62	63.51400948
Results									
Pump #	Tanks Included	Volume (Gal)	Total Head Loss	Installation Cost	Power consumpted	Hours of operation per day	Efficiency	Prices	
Pump 1	1,4	120000	108.2118812	$45,456	15.65 KW/h	3.2	81%	Total installation Cost	$90,912
Pump 2	2,5	120000	108.2118812	$45,456	15.65 KW/h	3.2	81%	Cost for 5 Years	$18,943.60
Pump 3	3	60000	79.08580587	$0	11.93 KW/h	1.6	65%	Net Cost	$109,855.60

Appendix 4: Taco Pump Performance Graph



Appendix 5: Equations used

Colebrook equation	*Headloss*	*Flow rate*
$\frac{1}{\sqrt{f}} = -2\log_{10}(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}})$	$H = \Delta z + \left(f\frac{L}{D} + \Sigma K_L\right)\frac{V^2}{2g}$	$\dot{V} = \frac{\pi}{4}d^2 V_{avg}$

Reynolds number	*Break Horsepower to Kilowatts*	*Work Electric*
$Re = \frac{\rho D V_{avg}}{\mu}$	$kW = \frac{W_{elec}}{550} * 0.74569$	$W_{elec} = \frac{\rho \dot{V} g h_L}{\eta_{pump}}$

Head Required

$$h_{pump,u} = \frac{P_2 - P_1}{\rho g} + \frac{\alpha_2 V_2^2 - \alpha_1 V_1^2}{2g} + (z_2 - z_1) + h_{L,total}$$

Cost in Years

$$Cost = \frac{\$rate}{kWhr}(kW * hr * 365 * years)$$

References

1. https://up.codes/viewer/texas/irc-2015/chapter/P/sizing-of-water-piping-system#P
2. https://up.codes/viewer/texas/ipc-2015/chapter/5/water-heaters#5
3. https://www.engineeringtoolbox.com/water-density-specific-weight-d_595.html
4. https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html?vA=70&units=F#