Optimal Operating Point and Efficiency of Solar- Gas Water Heater System

Fluid Mechanics - Team 8

MECH 3314

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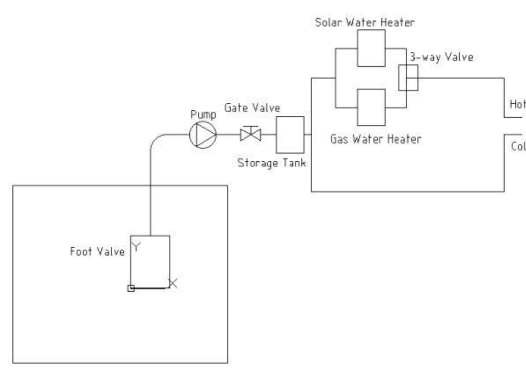
Introduction

For this project, the optimal operating point for a Solar-Gas Water heater system, is calculated as well as it's efficiency at that flow rate. The system includes a number of devices, such as the water pump, that increases the pressure change of water throughout the system depending on the increase in flow rate. For one of the hot water sources, a solar heater is incorporated due to it's a more eco-friendly alternative to heat the water in the system. A gas tank is also included in the system as a backup for when the solar heater does not output the desired hot water temperature. Some factors that play a key role in the calculations are the length of the piping system, number and types of pipe connectors, pipe diameter, K type copper piping material, water temperature, and velocity of water. By glimpsing into how engineers design and calculate a pump and pipe-line to work with the least amount of head losses and optimum flow rates one understands how engineers can increase efficiency of a system.This project's current practical significance can be seen in today's companies as they compete among themselves to be more eco friendly and cost efficient.

Theoretical Background

The goal in this project is to calculate the optimal operating point in a Solar-Gas Water heater piping system by calculating the pressure drops of flow rates between 0 to 40 gallons per minute. Pressure drop is the difference in pressure between two points in which a fluid is flowing while taking factors that may cause resistance to act on a fluid. From the pressure drop equation, $\Delta P_L = h_{L,total}\rho g$, one can see that $\rho \propto \Delta P$ and varying temperature in a system may cause changes in density. Additionally, $\Delta P \propto h_{L,total}$, where total head loss tells the loss in pressure due to forces acting on the system such as a pipe elbows which account for minor losses, and piping lengths for major losses, $h_{L,total} = h_{L.major} + h_{L,minor} = \Sigma f_i \frac{L_i}{D_i} \frac{V_i^2}{2g} + \Sigma K_{L,j} \frac{V_j^2}{2g}$. A key component in major losses is the friction factor, which is stated to be the ratio between the necessary force needed to move a section of a pipe in this case and the vertical force applied on the pipe. In order to find the friction factor, it is necessary to use the Colebrook equation $\frac{1}{\sqrt{f}} \approx -2log[\frac{6.9}{Re} + (\frac{\varepsilon/D}{3.7})^{1.11}]$, as was chosen for this project, or a Moody chart. Here another important term is Reynolds Number; this is a dimensionless parameter, and tells the ratio of inertial forces in comparison to viscous forces. Since this system deals with an internal flow it is important to consider the Reynolds Number because a number less than 2300 would indicate a laminar flow while anything over 4000 indicates turbulent flow. If Reynolds number falls in between these two values the flow is transitional, and the project would not be proceedable due to piping systems not being able to work under those conditions. Luckily with the assumptions made,Reynold's number for this system resulted in turbulent flow.

Schematic diagram:

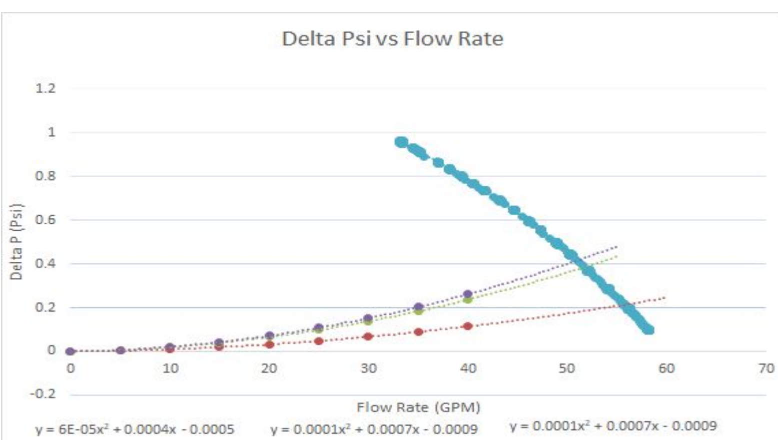


After designing a CAD of a house based on the blueprints of an actual El Paso house, the desired system was implemented. Next, various assumptions were made based on the Residential Code for one- and two-family dwellings of the Texas Industrialized Housing and Buildings Program (Reference 1) it was decided to use 3 inch diameter K copper tubing. It was learned that the size of this diameter really impacts the rate at which the fluid will flow, meaning if you have too big of a diameter more water will flow and if more fluid is flowing, that is more money flowing as well. There were many factors that to be considered when choosing the material such as the life expectancy, how the material performs in different weather conditions, and if it was eco-friendly (recyclable). Copper can be a bit more on the pricey side, but the quality of piping requires low maintenance and performed best in the latter categories. Lastly, a cold water temperature of 70 F and a hot water temperature of 140 F was chosen based on the Plumbing Code of the Texas Industrialized Housing and Buildings Program (Reference 2).

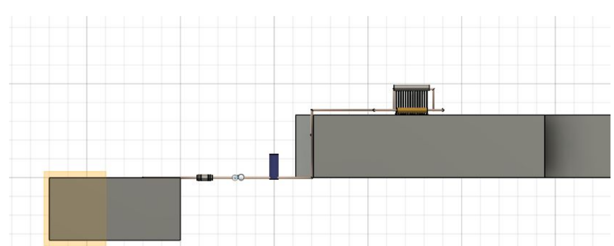
Results

The first step after making the assumptions of the temperatures, diameter, and material from the residential code for the state of Texas (Reference 1), it needed to be identified as the type of fluid. All of Reynold's numbers calculated were larger than 5000, resulting in Turbulent Flow. With this information, the coefficient of friction was calculated with Colebrook's equation (Appendix 6), ranging approximately from 0.0306 to 0.0217. The coefficient of friction is used along with the total length of each pipeline to calculate the Major Head Losses (Appendix E). When analyzing the CAD (Appendix 5), the following was counted: 90 degree elbows, T connections, gate valves, and length. With this information, the Minor Head Losses (Appendix 6) was obtained. The total Head Loss (sum of minor and major losses) will be used to find the pressure loss for each pipeline and each flow rate. After calculating the pressure drops for the cold water pipeline, the gas heater pipeline and the solar heater pipelines plot the Change in Pressure versus the Flow Rate. The operating point outputs the highest flow rate was (57.748GPM). Therefore, the pump ZOZHI NFM-130C works for all three water lines. This pump runs at a maximum flow rate of 160 GPM, has one of the lowest energy consumption in the market, and has the inlets and outlets of the diameter needed (Appendix 1). Methods of increasing efficiency is to decrease the energy consumption of the pipe (use less the maximum usage), to look for materials with smaller coefficients of roughness, modify the system to have less Major and Minor losses (ex. Decrease overall length, reduce 90 degree turns, etc…) and use other methods of water elevation.

Water Line Operating Points	Optimum Flow Rate (GPM)	Pressure (psi)	Efficiency%
Gas Heater Water Line	54.996	.3397	56.53%
Cold Water Line	57.748	.2270	38.97%
Solar Heater Water Line	54.966	.3397	56.53%



Change in Pressure versus Flow Rate



Left View, CAD

Appendix

Appendix 1: Water Pump Information

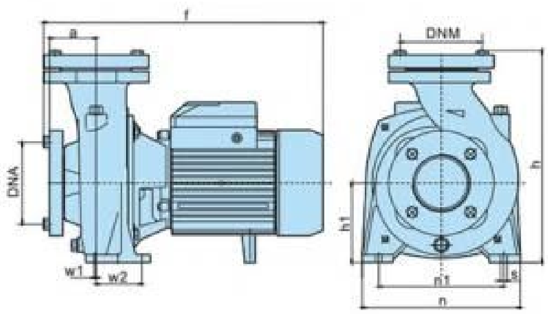
ZOZHI NFM-130C Electric Centrifugal Water Pump 1.5 HP

From 0 - 160 GPM

TECHNICAL DATA (220-240V/50Hz)

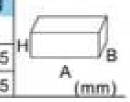
Model	Single-phase Motor				n=2850r/min		
	Input max	Output Power		Current	Q.max	H.max	Suct.max
	kW	kW	HP	A	L/min	m	m
NFM-128B	0.88	0.60	0.8	3.2	400	12.5	
NFM-128A	1.10	0.75	1.0	5.2	500	13.7	
NFM-129B	1.50	1.10	1.5	7.0	500	15	
NFM-129A	2.00	1.50	2.0	9.6	850	15	9
NFM-130C	1.50	1.10	1.5	7.0	600	12	
NFM-130B	2.00	1.50	2.0	9.6	850	13	
NFM-130A	2.90	2.20	3.0	13.9	1000	15	

Other voltages and frequencies available on request.



OVERALL & INSTALLATION DIMENSIONS

Model	DIMENSIONS (mm)														PACKAGE DIMENSIONS& G.W.			
	DNA		DNM		a	f	h	h1	i	n	n1	w1	w2	s	A	B	C	kg
	Inch	mm	Inch	mm														
NFM-128	2"	50	2"	50	65	334	271	97	264	196	160	8	60	12				
NFM-129	2"	50	2"	50	56	372	276	110	269	206	160	1	62	11	453	281	355	355
NFM-130	3"	75	3"	75	71	390	320	120	313	240	190	6	66	12	453	281	355	355



Appendix 2: Excel Calculations

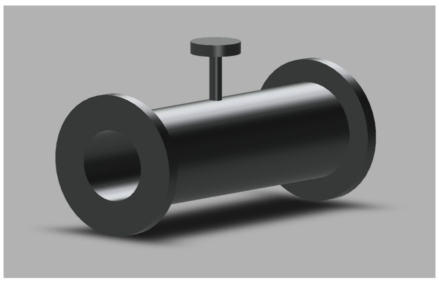
Pipeline 1: K- Copper, 3-inch Pipe for Water at 70 F										
Assumptions:	Temperature (F):	70	Componets:	Equations:	Flow Rate	Re	Friction Factor	Major Losses	Minor Losses	Pressure Loss
	Diameter (ft)	0.25	2 Elbows							
	Area (ft^2)	0.04908738521	1 T- elbow							
	density cold (lbm/ft^3)	62.3	Gate Valve							
	Dynamic Viscosity cold	6.56E-04	Foot Valve		$\dot{V}=\frac{\pi}{4}d^2V_{avg}$	$Re = \frac{\rho D V_{avg}}{\mu}$	$\frac{1}{\sqrt{f}} = -2\log_{10}(\frac{\varepsilon/D}{3.7}+\frac{2.51}{Re\sqrt{f}})$	$h_{L,Major} = f\left(\frac{L}{D}\right)\frac{V^2}{2g}$	$h_L = K\frac{V^2}{2g}$	$h_L = \frac{\Delta P}{\rho g}$
	Gravity (ft/s^2)	32.2								
Flow Rate (GPM)	Flow Rate ft^3/s	Velocity ft/s	Lenght (ft)	Re	Friction Factor	Major Losses (ft)	KL	Minor Losses (ft)	Head Loss (ft)	Pressure Loss (psi)
0	0	0	46.91	0	0	0	1.1	0	0	0
5	0.01114	0.2269422165	46.91	5391.435359	0.03662399	0.005495861731	1.1	0.000879705692	0.006375567424	0.002760531337
10	0.0222801	0.4538864701	46.91	10782.91911	0.03031240236	0.01819509754	1.1	0.003518854356	0.006375567424	0.009366989241
15	0.0334201	0.6808286865	46.91	16174.35447	0.02732621095	0.0369058036	1.1	0.00791739861	0.01275113485	0.0193358839
20	0.0445602	0.9077729402	46.91	21565.83823	0.02546039797	0.06113067766	1.1	0.01407541742	0.01912670227	0.03244249076
25	0.0557002	1.134715157	46.91	26957.27359	0.02413874155	0.09055822332	1.1	0.02199280024	0.03187783712	0.04855238844
30	0.0668403	1.36165941	46.91	32348.75734	0.02313238837	0.1249674809	1.1	0.0316696892	0.05100453939	0.06757032044
35	0.0779803	1.588601627	46.91	37740.1927	0.0223291424	0.1641880731	1.1	0.04310591058	0.08288237651	0.08942271425
40	0.0891204	1.81554588	46.91	43131.67646	0.02166634282	0.2080844487	1.1	0.05630166969	0.1338869159	0.1140511842
Results										
Results:	Optimal Flow Rate	57.748	Pressure Loss	0.227	Head Loss	0.000111163175	Efficiency	38.97%	Equation	$\eta_{Pump-motor} = \frac{\rho \dot{V} g h_L}{\dot{W}_{electric}}$

Pipeline 2: K- Copper, 3-inch Pipe for Water at 140 F for the Gas Heater											
Assumptions:	Temperature (F):	140	Componets:	Equations:	Flow Rate	Re	Friction Factor		Major Losses	Minor Losses	Pressure Loss
	Diameter (ft)	0.25	8 Elbows								
	Area (ft^2)	0.04908738521	2 T- elbow								
	density hot (lbm/ft^3)	61.38	Foot Valve								
	Dynamic Viscosity cold	3.14E-04	Gate Valve		$\dot{V} = \frac{\pi}{4} d^2 V_{avg}$	$Re = \frac{\rho D V_{avg}}{\mu}$	$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$		$h_{L,Major} = f\left(\frac{L}{D}\right)\frac{V^2}{2g}$	$h_L = K\frac{V^2}{2g}$	$h_L = \frac{\Delta P}{\rho g}$
	Gravity (ft/s^2)	32.2	Gate Valve								
Flow Rate (GPM)	Flow Rate ft^3/s	Velocity ft/s	Lenght (ft)	Re	Friction Factor	Major Losses (ft)	KL		Minor Losses (ft)	Head Loss (ft)	Pressure Loss (psi)
0	0	0	101.9772	0	0	0		3.25	0	0	0
5	0.01114	0.2269422165	101.9772	11104.68212	0.03007522516	0.009811076882		3.25	0.002599130454	0.01241020734	0.005294116868
10	0.0222801	0.4538864701	101.9772	22209.46391	0.02527651852	0.03298290753		3.25	0.01039661514	0.04337952268	0.01850543319
15	0.0334201	0.6808286865	101.9772	33314.14603	0.02297265996	0.06744724023		3.25	0.02339231407	0.0908395543	0.03875158599
20	0.0445602	0.9077729402	101.9772	44418.92783	0.02152138	0.1123315596		3.25	0.04158646057	0.1539180201	0.06566046519
25	0.0557002	1.134715157	101.9772	55523.60994	0.0204879	0.1670891942		3.25	0.06497872798	0.2320679222	0.09899872487
30	0.0668403	1.36165941	101.9772	66628.39174	0.01969796	0.2313318559		3.25	0.09356953628	0.3249013922	0.1386009028
35	0.0779803	1.588601627	101.9772	77733.07386	0.01906562	0.304760127		3.25	0.1273583722	0.4321184992	0.1843390504
40	0.0891204	1.81554588	101.9772	88837.85566	0.01854267	0.3871363342		3.25	0.1663458423	0.5534821764	0.2361120364
Results											
Results:	Optimal Flow Rate	54.996	Pressure Loss	0.3397	Head Loss	0.000171875031	Efficiency		56.53%	Equation	$\eta_{Pump-motor} = \frac{\rho V g h_L}{\dot{W}_{electric}}$

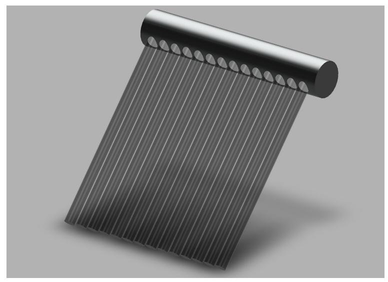
Pipeline 3: K- Copper, 3-inch Pipe for Water at 140 F for the Solar Heater											
Assumptions:	Temperature (F):	140	Componets:	Equations:	Flow Rate	Re	Friction Factor		Major Losses	Minor Losses	Pressure Loss
	Diameter (ft)	0.25	11 Elbows								
	Area (ft^2)	0.04908738521	2 T- elbow								
	density hot (lbm/ft^3)	61.38	Foot Valve								
	Dynamic Viscosity cold	3.14E-04	Gate Valve		$\dot{V} = \frac{\pi}{4} d^2 V_{avg}$	$Re = \frac{\rho D V_{avg}}{\mu}$	$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$		$h_{L,Major} = f\left(\frac{L}{D}\right)\frac{V^2}{2g}$	$h_L = K\frac{V^2}{2g}$	$h_L = \frac{\Delta P}{\rho g}$
	Gravity (ft/s^2)	32.2	Gate Valve								
Flow Rate (GPM)	Flow Rate ft^3/s	Velocity ft/s	Lenght (ft)	Re	Friction Factor	Major Losses (ft)	KL		Minor Losses (ft)	Head Loss (ft)	Pressure Loss (psi)
0	0	0	105.427	0	0	0		4.15	0	0	0
5	0.01114	0.2269422165	105.427	11104.68212	0.03007522516	0.01014297708		4.15	0.003318889656	0.01346186674	0.005742724249
10	0.0222801	0.4538864701	105.427	22209.46391	0.02527651852	0.03409869062		4.15	0.0132756778	0.04737436841	0.02020960941
15	0.0334201	0.6808286865	105.427	33314.14603	0.02297265996	0.06972892172		4.15	0.02987018566	0.09959910738	0.04248835657
20	0.0445602	0.9077729402	105.427	44418.92783	0.02152138	0.1161316386		4.15	0.05310271119	0.1692343497	0.07219431565
25	0.0557002	1.134715157	105.427	55523.60994	0.0204879	0.1727416764		4.15	0.08297283726	0.2557145137	0.109086213
30	0.0668403	1.36165941	105.427	66628.39174	0.01969796	0.2391576114		4.15	0.1194811002	0.3586387116	0.1529930324
35	0.0779803	1.588601627	105.427	77733.07386	0.01906562	0.3150698971		4.15	0.1626268445	0.4776967416	0.2037824437
40	0.0891204	1.81554588	105.427	88837.85566	0.01854267	0.4002328197		4.15	0.2124108447	0.6126436645	0.2613499574
Results											
Results:	Optimal Flow Rate	54.996	Pressure Loss	0.3397	Head Loss	0.000171875031	Efficiency		56.53%	Equation	$\eta_{Pump-motor} = \frac{\rho V g h_L}{\dot{W}_{electric}}$

Appendix 4: Components

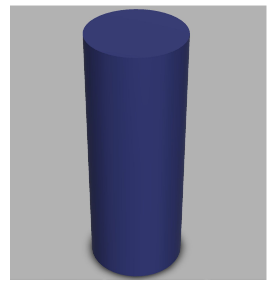
Gate Valve



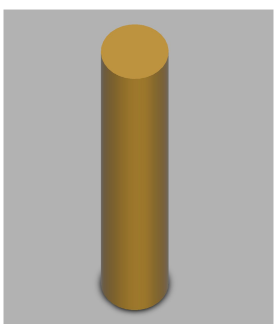
Solar Heater



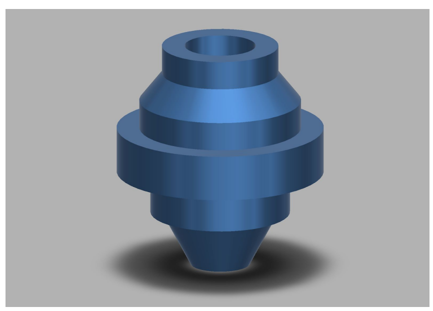
Water Storage



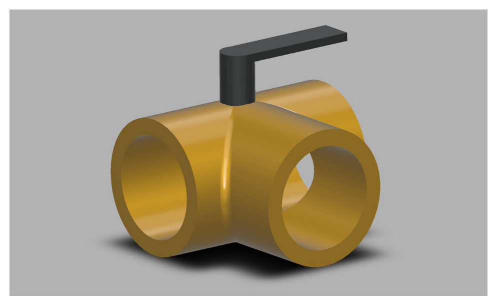
Gas Heater



Foot Valve

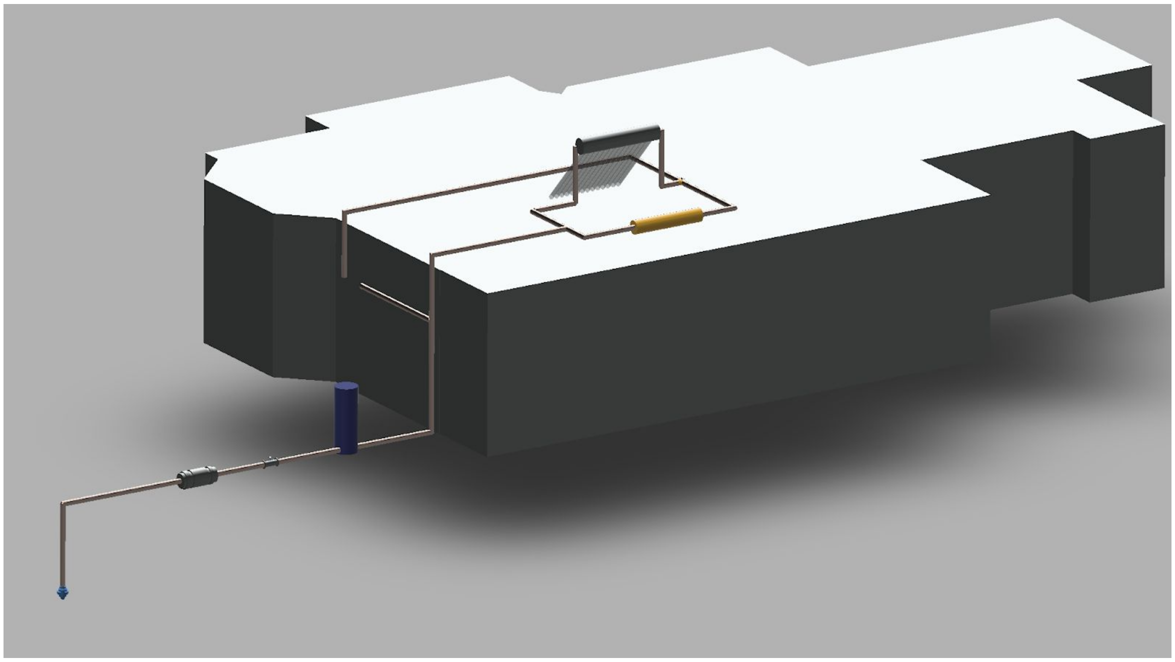


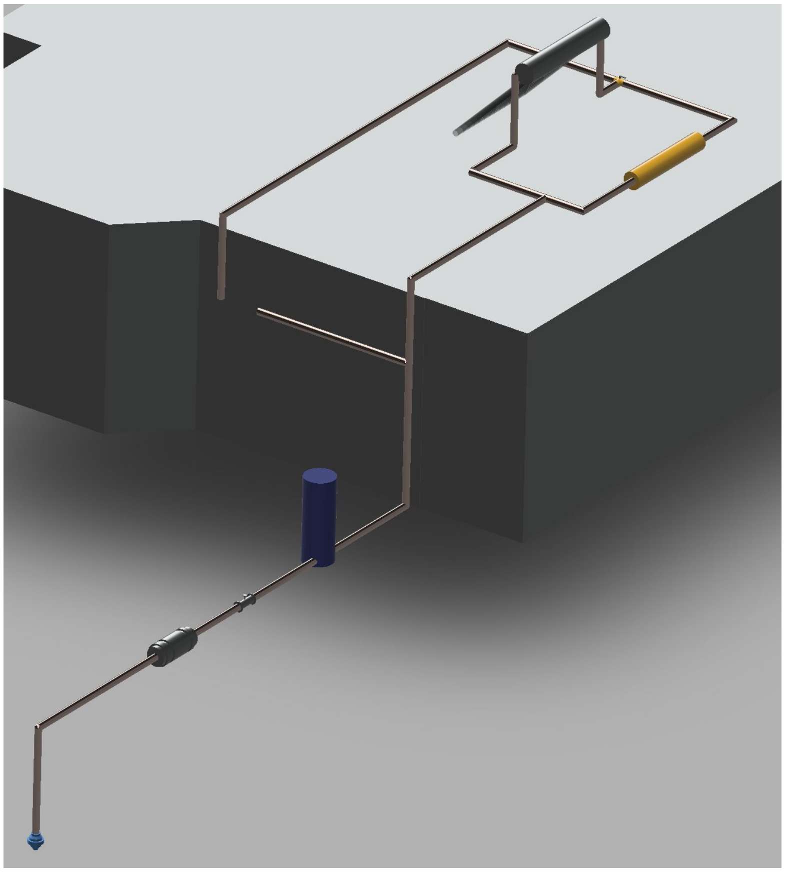
3-way Valve



Water Pump

Appendix 5: CAD House Containing all Components





Appendix 6: Equations used

$\eta_{Pump-motor} = \frac{\rho V g h_L}{\dot{W}_{electric}}$ **Pump efficiency**	$\dot{V} = \frac{\pi}{4} d^2 V_{avg}$ **Volume Flow Rate**	$h_L = \frac{\Delta P}{\rho g}$ **Head Loss**
$h_L = K \frac{V^2}{2g}$ **Minor Head Loss**	$h_{L,Major} = f\left(\frac{L}{D}\right)\frac{V^2}{2g}$ **Major Head Loss**	$Re = \frac{\rho D V_{avg}}{\mu}$ **Reynold's Number**

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$ **Colebrook Equation**		

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
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5. https://www.electricmotorwaterpump.com/sale-10956583-nfm-130c-electric-centrifugal-water-pump-1-5-hp-1-1kw-for-household-water-boosting.html