Pumping and Piping Design Project

1. Executive Summary

This report will outline the design of the source side pumping system for a golf course cooling system. It was overdesigned to ensure proper operation after repairs will operate adequately.

The following sections will detail how headloss is found for the heat pumps and the error corrlated with those calculation, The pumping system design, how the headloss was calculated and how the pumps were selcted, comparing the calculated pump curve to the manufacture data, a system P&ID and headloss summary, a method to automate headloss calculations, and operating power consumption.

2. Calculate and Analyze Heat Pump Headloss

Question 2 requires the designer to determine the headloss of the Climate Master Tranquility TMW060 and TMW120 heat pumps, and then calculate the K values for each heat pump. The first step to finding the headloss of a heat pump is calculating the refrigerant correction factor. For this paper, the heat pumps operate with 15% Propylene-Glycol by weight and have an average entering fluid temperature of 80F. Using this information and the data provided in Fig.1 it is possible to find the proper correction factor.
The next step is calculating the headloss at the designs specified flow and temperature using the manufacture data. Given the manfufacture data for the Climate Master TMW Tranquility series the designer need interpolate the data once to find the headloss at the correct flowrate, then they needed to interpolate again to find the headloss at the correct temperature. Lastly, the calculated headloss must be multiplied by the refrigerant correction factor that was found above.
The problem statement also required the designer to find the K value associated with each heat pump. The K value is proportional to the headloss multiplied by two time the acceleration due to gravity and divided by the velocity of the fluid squared.
All of the calculations described above are shown below. The calculations for the TMW060 Fig.2, Fig.3, and Fig.4. The calculations for the TMW060 Fig.5, Fig.6, and Fig.7. Lastly, it is important for designers to analyze the accuracy of their models. Using the K value calculated the designer developed a model for a headloss as a function of flowrate and compared the results to the values given in the manufactures data. Using a python script the comparisons were plotted and can be observed in Fig.8 and Fig.9 for the TMW060 and TMW120 respectively.
An accurate K value is important because for each percent error from the manufacture value, directly correlates to error for teh heat pump headloss.

EWT	Antifreeze Type	Antifreeze %	Cooling			Heating		WPD
			Total Cap	Sensible Cap	Watts	Total Cap	Watts	
90	Water	0%	1	1	1	1	1	1
	Ethanol	5%	0.998	0.998	1.002	0.996	0.999	1.025
		10%	0.996	0.996	1.003	0.991	0.997	1.048
		15%	0.994	0.994	1.005	0.987	0.996	1.098
		20%	0.991	0.991	1.006	0.982	0.994	1.142
		25%	0.986	0.986	1.009	0.972	0.991	1.207
		30%	0.981	0.981	1.012	0.962	0.988	1.265
		35%	0.977	0.977	1.015	0.953	0.985	1.312
		40%	0.972	0.972	1.018	0.943	0.982	1.37
		45%	0.966	0.966	1.023	0.931	0.978	1.431
		50%	0.959	0.959	1.027	0.918	0.974	1.494
	Ethylene Glycol	5%	0.998	0.998	1.002	0.996	0.999	1.021
		10%	0.996	0.996	1.003	0.991	0.997	1.04
		15%	0.994	0.994	1.004	0.987	0.996	1.079
		20%	0.991	0.991	1.005	0.982	0.995	1.114
		25%	0.988	0.988	1.008	0.976	0.993	1.146
		30%	0.985	0.985	1.01	0.969	0.99	1.175
		35%	0.982	0.982	1.012	0.963	0.988	1.208
		40%	0.979	0.979	1.014	0.956	0.986	1.243
		45%	0.976	0.976	1.016	0.95	0.984	1.278
		50%	0.972	0.972	1.018	0.943	0.982	1.314
	Methanol	5%	0.997	0.997	1.002	0.993	0.998	1.039
		10%	0.993	0.993	1.004	0.986	0.996	1.075
		15%	0.99	0.99	1.007	0.979	0.994	1.116
		20%	0.986	0.986	1.009	0.972	0.991	1.154
		25%	0.982	0.982	1.012	0.964	0.989	1.189
		30%	0.978	0.978	1.014	0.955	0.986	1.221
		35%	0.974	0.974	1.017	0.947	0.984	1.267
		40%	0.97	0.97	1.02	0.939	0.981	1.31
		45%	0.966	0.966	1.023	0.93	0.978	1.353
		50%	0.961	0.961	1.026	0.92	0.975	1.398
	Propylene Glycol	5%	0.995	0.995	1.003	0.99	0.997	1.065
		10%	0.99	0.99	1.006	0.98	0.994	1.119
		15%	0.986	0.986	1.009	0.971	0.991	1.152
		20%	0.981	0.981	1.012	0.962	0.988	1.182
		25%	0.978	0.978	1.014	0.956	0.986	1.227
		30%	0.975	0.975	1.016	0.95	0.984	1.267
		35%	0.972	0.972	1.018	0.944	0.982	1.312
		40%	0.969	0.969	1.02	0.938	0.98	1.356
		45%	0.965	0.965	1.023	0.929	0.977	1.402
		50%	0.96	0.96	1.026	0.919	0.974	1.45

Fig.1 - Refrigerant Correction Values

SOURCE				LOAD																					
EWT °F	Flow			EWT °F	Flow 7.5 GPM							Flow 11.25 GPM							Flow 15.0 GPM						
	GPM	WPD			TC Mbtuh	Power kW	HR Mbtuh	LWT °F	EER	WPD		TC Mbtuh	Power kW	HR Mbtuh	LWT °F	EER	WPD		TC Mbtuh	Power kW	HR Mbtuh	LWT °F	EER	WPD	
		PSI	FT							PSI	FT						PSI	FT						PSI	FT
50	7.5	1.3	2.9	50	52.6	2.20	60.1	38.2	23.9	1.4	3.3	53.5	2.23	61.1	41.0	24.0	3.5	8.0	55.3	2.25	63.0	42.5	24.6	4.8	11.0
				60	53.2	2.22	60.8	47.1	23.9	1.4	3.2	54.1	2.25	61.7	50.5	24.1	3.3	7.7	55.9	2.27	63.7	52.4	24.7	4.6	10.6
				70	53.8	2.24	61.4	56.0	24.0	1.3	3.0	54.7	2.26	62.4	60.0	24.1	3.2	7.4	56.6	2.29	64.4	62.2	24.7	4.4	10.1
				80	55.5	2.24	63.2	64.7	24.7	1.2	2.9	56.4	2.27	64.1	69.4	24.9	3.1	7.1	58.4	2.29	66.2	72.0	25.5	4.3	9.8
				90	57.2	2.25	64.9	73.5	25.5	1.2	2.7	58.1	2.27	65.9	78.9	25.6	3.0	6.9	60.2	2.29	68.0	81.8	26.3	4.1	9.5
	11.25	3.4	7.9	50	53.4	2.23	61.0	38.0	24.0	1.4	3.3	54.1	2.25	61.8	40.8	24.1	3.5	8.0	56.0	2.27	63.8	42.3	24.7	4.8	11.0
				60	55.5	2.25	63.1	46.7	24.7	1.4	3.2	56.2	2.27	64.0	50.1	24.8	3.3	7.7	58.2	2.29	66.0	52.0	25.4	4.6	10.6
				70	57.5	2.26	65.3	55.4	25.4	1.3	3.0	58.3	2.29	66.1	59.4	25.5	3.2	7.4	60.4	2.31	68.3	61.6	26.1	4.4	10.2
				80	58.1	2.27	65.8	64.3	25.6	1.2	2.9	58.9	2.29	66.7	69.0	25.7	3.1	7.1	60.9	2.31	68.8	71.5	26.4	4.3	9.8
				90	58.6	2.27	66.3	73.2	25.8	1.2	2.7	59.4	2.29	67.2	78.5	25.9	3.0	6.9	61.5	2.31	69.4	81.4	26.6	4.1	9.5
	15.0	6.2	14.2	50	55.6	2.25	63.2	35.8	24.7	1.4	3.3	56.5	2.27	64.2	40.3	24.9	3.5	8.0	57.9	2.29	65.8	42.1	25.2	4.8	11.1
				60	57.5	2.27	65.2	45.0	25.3	1.4	3.2	58.7	2.29	66.6	49.8	25.6	3.3	7.7	61.5	2.31	69.4	51.5	26.6	4.6	10.6
				70	59.4	2.29	67.2	54.1	26.0	1.3	3.0	61.0	2.31	68.9	59.3	26.4	3.2	7.4	65.1	2.33	73.1	60.9	27.9	4.4	10.1
				80	60.3	2.29	68.1	63.5	26.4	1.2	2.9	61.8	2.31	69.7	68.7	26.7	3.1	7.1	65.8	2.34	73.8	70.8	28.2	4.2	9.8
				90	61.3	2.29	69.1	72.8	26.7	1.2	2.7	62.6	2.31	70.5	78.1	27.0	3.0	6.9	66.6	2.34	74.6	80.7	28.5	4.1	9.4
70	7.5	1.1	2.5	50	49.1	2.82	58.7	38.1	17.4	1.4	3.3	50.3	2.85	60.0	41.1	17.7	3.5	8.0	52.0	2.88	61.8	42.9	18.1	4.7	11.0
				60	53.2	2.84	62.9	46.4	18.7	1.4	3.2	54.5	2.87	64.3	50.0	19.0	3.3	7.7	56.3	2.90	66.2	52.3	19.4	4.6	10.5
				70	57.2	2.86	67.0	54.8	20.0	1.3	3.0	58.7	2.89	68.5	59.1	20.3	3.2	7.4	60.6	2.92	70.6	61.7	20.8	4.4	10.1
				80	59.3	2.92	69.3	63.4	20.3	1.2	2.9	60.8	2.95	70.9	68.3	20.6	3.1	7.1	62.9	2.98	73.0	71.4	21.1	4.3	9.8
				90	61.4	2.98	71.6	71.9	20.6	1.2	2.7	63.0	3.01	73.3	77.6	20.9	3.0	6.9	65.1	3.04	75.5	81.1	21.4	4.1	9.5
	11.25	3.0	6.9	50	50.2	2.85	59.9	38.0	17.6	1.4	3.3	51.4	2.88	61.2	41.0	17.8	3.5	8.0	53.1	2.91	63.0	42.8	18.3	4.8	11.0
				60	54.5	2.87	64.3	46.2	19.0	1.4	3.2	55.9	2.90	65.8	49.8	19.3	3.3	7.7	57.7	2.93	67.7	52.1	19.7	4.6	10.6
				70	58.9	2.89	68.8	54.5	20.4	1.3	3.0	60.4	2.92	70.3	58.8	20.7	3.2	7.4	62.4	2.94	72.4	61.4	21.2	4.4	10.2
				80	60.8	2.95	70.8	63.1	20.6	1.2	2.9	62.3	2.98	72.4	68.1	20.9	3.1	7.1	64.4	3.01	74.6	71.1	21.4	4.3	9.9
				90	62.6	3.01	72.9	71.7	20.8	1.2	2.7	64.2	3.04	74.5	77.3	21.1	3.0	6.9	66.3	3.07	76.8	80.8	21.6	4.1	9.6
	15.0	5.5	12.8	50	51.2	2.88	61.0	36.9	17.8	1.4	3.3	53.3	2.91	63.2	40.8	18.3	3.5	8.0	54.3	2.94	64.3	42.6	18.5	4.8	11.0
				60	55.6	2.90	65.5	45.4	19.2	1.4	3.2	57.6	2.93	67.6	49.6	19.7	3.3	7.7	59.4	2.96	69.5	51.8	20.1	4.6	10.6
				70	60.1	2.92	70.1	53.9	20.6	1.3	3.0	61.9	2.94	72.0	58.5	21.0	3.2	7.4	64.5	2.97	74.6	61.1	21.7	4.4	10.1
				80	62.3	2.98	72.5	62.7	20.9	1.2	2.9	64.1	3.01	74.4	67.8	21.3	3.1	7.1	67.1	3.04	77.5	70.6	22.1	4.2	9.8
				90	64.6	3.04	74.9	71.5	21.3	1.2	2.7	66.3	3.07	76.8	77.1	21.6	3.0	6.9	69.8	3.10	80.3	80.2	22.5	4.1	9.5
90	7.5	0.9	2.1	50	44.8	3.57	57.0	38.7	12.5	1.4	3.3	46.3	3.61	58.6	41.6	12.8	3.5	8.0	47.5	3.65	59.9	43.4	13.0	4.7	10.9
				60	50.7	3.61	63.0	46.8	14.0	1.4	3.2	52.3	3.65	64.8	50.3	14.3	3.3	7.7	53.7	3.68	66.3	52.6	14.6	4.5	10.5
				70	56.6	3.65	69.0	54.9	15.5	1.3	3.0	58.4	3.69	70.9	59.1	15.8	3.2	7.4	59.9	3.72	72.6	61.8	16.1	4.4	10.1
				80	59.6	3.73	72.4	63.4	16.0	1.2	2.9	61.5	3.77	74.4	68.2	16.3	3.1	7.1	63.1	3.81	76.1	71.3	16.6	4.3	9.8
				90	62.7	3.82	75.7	71.9	16.4	1.2	2.7	64.7	3.86	77.9	77.3	16.8	3.0	6.9	66.4	3.90	79.7	80.9	17.0	4.1	9.6
	11.25	2.7	6.1	50	45.9	3.61	58.2	38.6	12.7	1.4	3.3	47.4	3.65	59.8	41.5	13.0	3.5	8.0	48.6	3.68	61.2	43.4	13.2	4.8	11.0
				60	51.8	3.65	64.3	46.7	14.2	1.4	3.2	53.5	3.68	66.0	50.2	14.5	3.3	7.7	54.9	3.72	67.6	52.5	14.7	4.6	10.6
				70	57.7	3.69	70.3	54.8	15.7	1.3	3.0	59.6	3.72	72.3	58.9	16.0	3.2	7.4	61.1	3.76	73.9	61.6	16.2	4.4	10.2
				80	60.7	3.77	73.6	63.2	16.1	1.2	2.9	62.6	3.81	75.7	68.0	16.4	3.1	7.1	64.3	3.85	77.4	71.1	16.7	4.3	9.9
				90	63.7	3.86	76.9	71.7	16.5	1.2	2.7	65.7	3.90	79.0	77.1	16.9	3.0	6.9	67.4	3.94	80.9	80.6	17.1	4.1	9.6
	15.0	5.0	11.6	50	46.5	3.65	59.0	38.1	12.8	1.4	3.3	48.6	3.68	61.1	41.4	13.2	3.5	8.0	49.5	3.72	62.2	43.3	13.3	4.7	10.9
				60	52.4	3.68	64.9	46.2	14.2	1.4	3.2	54.2	3.72	66.9	50.1	14.6	3.3	7.7	55.8	3.76	68.6	52.4	14.8	4.6	10.5
				70	58.2	3.72	70.9	54.3	15.6	1.3	3.0	59.8	3.76	72.7	58.7	15.9	3.2	7.4	62.0	3.80	75.0	61.5	16.3	4.4	10.1
				80	61.6	3.81	74.6	62.9	16.2	1.2	2.9	63.4	3.85	76.6	67.8	16.5	3.1	7.1	65.8	3.89	79.0	70.8	16.9	4.3	9.8
				90	65.1	3.90	78.4	71.6	16.7	1.2	2.7	67.0	3.94	80.5	77.0	17.0	3.0	6.9	69.5	3.98	83.1	80.2	17.5	4.1	9.5

Fig.2 - TWM060 Manufacture Data

1 Finding Headloss of TMW060 @ 80F and 9 GPM

2 Headloss of TMW060 @ 70F and 9GPM w/ Water

3
$$2.5+(9-7.5)\left(\frac{6.9-2.5}{11.25-7.5}\right)$$
$$=4.26$$

4 Headloss of TMW060 @ 90F and 9GPM w/ Water

5
$$2.1+(9-7.5)\left(\frac{6.1-2.1}{11.25-7.5}\right)$$
$$=3.7$$

6 Correction Factor for 15% Propylene-Glycol

7
$$k=1.152$$
−10 10

8 Headloss of TMW060 @ 80F and 9GPM w/ 15% Propylene-Glycol

9
$$\left(4.26+(80-70)\left(\frac{3.7-4.26}{90-70}\right)\right)\cdot k$$
$$=4.58496$$

Fig.3 - Calculate Headloss of TMW060

1 Estimating the K value Corresponding to the Piping Size for TMW060

2 Headloss for TMW060 @ 80F and 9GPM

3 $H = 4.58496$

−10 10

4 Velocity of 15% Propylene-Glycol in 2" SDR-11 2" Pipes @ 9GPM in ft^3/min

5 $$V = \frac{9 \cdot 0.133681}{0.020}$$

$V = 60.15645$

6 Acceleration due to Gravity in ft/min^2

7 $$g = 32.2\left(\frac{3600}{1}\right)$$

$g = 115920$

8 K value Corresponding to the Piping Size for TMW060

9 $$K = \frac{H}{V^2} 2g$$

$K = 293.737585354$

Fig.4 - Calculate K Value for TMW060

SOURCE				LOAD																					
EWT °F	Flow			EWT °F	Flow 15.0 GPM							Flow 22.5 GPM							Flow 30.0 GPM						
	GPM	WPD PSI	WPD FT		TC Mbtuh	Power kW	HR Mbtuh	LWT °F	EER	WPD PSI	WPD FT	TC Mbtuh	Power kW	HR Mbtuh	LWT °F	EER	WPD PSI	WPD FT	TC Mbtuh	Power kW	HR Mbtuh	LWT °F	EER	WPD PSI	WPD FT
				50	105.2	4.41	120.3	38.2	23.9	1.6	3.7	106.9	4.45	122.1	41.0	24.0	3.8	8.8	110.7	4.50	126.0	42.5	24.6	6.8	15.7
				60	106.4	4.45	121.6	47.1	23.9	1.5	3.5	108.1	4.49	123.4	50.5	24.1	3.7	8.4	111.9	4.54	127.4	52.4	24.7	6.6	15.2
	15.0	1.4	3.2	70	107.6	4.48	122.9	56.0	24.0	1.4	3.3	109.3	4.53	124.8	60.0	24.1	3.5	8.1	113.1	4.57	128.7	62.2	24.7	6.4	14.7
				80	111.0	4.49	126.3	64.7	24.7	1.4	3.2	112.8	4.53	128.3	69.4	24.9	3.4	7.9	116.7	4.58	132.4	72.0	25.5	6.2	14.3
				90	114.4	4.49	129.8	73.5	25.5	1.3	3.0	116.3	4.54	131.8	78.9	25.6	3.3	7.6	120.3	4.58	136.0	81.8	26.3	6.0	13.9
				50	106.8	4.45	122.0	38.0	24.0	1.6	3.7	108.3	4.50	123.6	40.8	24.1	3.8	8.8	112.1	4.54	127.6	42.3	24.7	6.8	15.7
				60	110.9	4.49	126.2	46.7	24.7	1.5	3.5	112.5	4.54	128.0	50.1	24.8	3.7	8.4	116.4	4.58	132.0	52.0	25.4	6.6	15.2
50	22.5	3.8	8.7	70	115.1	4.53	130.5	55.4	25.4	1.4	3.3	116.7	4.57	132.3	59.4	25.5	3.5	8.1	120.8	4.62	136.5	61.6	26.1	6.4	14.7
				80	116.1	4.53	131.6	64.3	25.6	1.4	3.2	117.7	4.58	133.4	69.0	25.7	3.4	7.9	121.9	4.62	137.6	71.5	26.4	6.2	14.3
				90	117.2	4.54	132.6	73.2	25.8	1.3	3.0	118.8	4.58	134.5	78.5	25.9	3.3	7.6	123.0	4.63	138.8	81.4	26.6	6.0	13.9
				50	111.1	4.50	126.5	35.8	24.7	1.6	3.7	113.0	4.54	128.5	40.3	24.9	3.8	8.8	115.9	4.59	131.5	42.1	25.2	6.8	15.7
				60	114.9	4.54	130.4	45.0	25.3	1.5	3.5	117.5	4.58	133.1	49.8	25.6	3.7	8.4	123.0	4.63	138.8	51.5	26.6	6.6	15.2
	30.0	6.8	15.6	70	118.8	4.57	134.4	54.1	26.0	1.4	3.3	122.0	4.62	137.8	59.3	26.4	3.5	8.1	130.2	4.67	146.1	60.9	27.9	6.4	14.7
				80	120.7	4.58	136.3	63.5	26.4	1.4	3.2	123.6	4.62	139.4	68.7	26.7	3.4	7.9	131.7	4.67	147.6	70.8	28.2	6.2	14.3
				90	122.5	4.58	138.2	72.8	26.7	1.3	3.0	125.2	4.63	141.0	78.1	27.0	3.3	7.6	133.2	4.68	149.1	80.7	28.5	6.0	13.9
				50	98.2	5.64	117.5	38.1	17.4	1.6	3.7	100.6	5.70	120.1	41.1	17.7	3.8	8.8	104.0	5.76	123.7	42.9	18.1	6.8	15.7
				60	106.3	5.68	125.7	46.4	18.7	1.5	3.5	109.0	5.74	128.6	50.0	19.0	3.7	8.4	112.6	5.79	132.4	52.3	19.4	6.6	15.2
	15.0	1.2	2.7	70	114.4	5.71	133.9	54.8	20.0	1.4	3.3	117.3	5.77	137.0	59.1	20.3	3.5	8.1	121.3	5.83	141.2	61.7	20.8	6.4	14.7
				80	118.7	5.83	138.6	63.4	20.3	1.4	3.2	121.7	5.89	141.8	68.3	20.6	3.4	7.9	125.7	5.95	146.1	71.4	21.1	6.2	14.3
				90	122.9	5.95	143.2	71.9	20.6	1.3	3.0	126.0	6.02	146.5	77.6	20.9	3.3	7.6	130.2	6.08	151.0	81.1	21.4	6.0	13.9
				50	100.3	5.70	119.8	38.0	17.6	1.6	3.7	102.7	5.76	122.4	41.0	17.8	3.8	8.8	106.2	5.82	126.0	42.8	18.3	6.8	15.7
				60	109.1	5.74	128.7	46.2	19.0	1.5	3.5	111.7	5.79	131.5	49.8	19.3	3.7	8.4	115.5	5.85	135.4	52.1	19.7	6.6	15.2
70	22.5	3.3	7.6	70	117.9	5.77	137.6	54.5	20.4	1.4	3.3	120.7	5.83	140.6	58.8	20.7	3.5	8.1	124.8	5.89	144.9	61.4	21.2	6.4	14.7
				80	121.6	5.89	141.7	63.1	20.6	1.4	3.2	124.5	5.95	144.9	68.1	20.9	3.4	7.9	128.7	6.01	149.2	71.1	21.4	6.2	14.3
				90	125.2	6.02	145.8	71.7	20.8	1.3	3.0	128.3	6.08	149.1	77.3	21.1	3.3	7.6	132.6	6.14	153.6	80.8	21.6	6.0	13.9
				50	102.4	5.76	122.0	36.9	17.8	1.6	3.7	106.6	5.82	126.4	40.8	18.3	3.8	8.8	108.5	5.88	128.6	42.6	18.5	6.8	15.7
				60	111.3	5.79	131.1	45.4	19.2	1.5	3.5	115.2	5.85	135.2	49.6	19.7	3.7	8.4	118.8	5.91	138.9	51.8	20.1	6.6	15.2
	30.0	6.1	14.1	70	120.2	5.83	140.1	53.9	20.6	1.4	3.3	123.9	5.89	144.0	58.5	21.0	3.5	8.1	129.0	5.95	149.3	61.1	21.7	6.4	14.7
				80	124.7	5.95	145.0	62.7	20.9	1.4	3.2	128.3	6.01	148.8	67.8	21.3	3.4	7.9	134.3	6.07	155.0	70.6	22.1	6.2	14.3
				90	129.1	6.08	149.9	71.5	21.3	1.3	3.0	132.6	6.14	153.6	77.1	21.6	3.3	7.6	139.5	6.20	160.7	80.2	22.5	6.0	13.9
				50	89.7	7.15	114.1	38.7	12.5	1.6	3.7	92.5	7.22	117.2	41.6	12.8	3.8	8.8	95.0	7.29	119.8	43.4	13.0	6.8	15.7
				60	101.4	7.22	126.0	46.8	14.0	1.5	3.5	104.6	7.30	129.5	50.3	14.3	3.7	8.4	107.4	7.37	132.5	52.6	14.6	6.6	15.2
	15.0	1.0	2.3	70	113.1	7.30	138.0	54.9	15.5	1.4	3.3	116.7	7.37	141.9	59.1	15.8	3.5	8.1	119.8	7.45	145.2	61.8	16.1	6.4	14.7
				80	119.3	7.47	144.8	63.4	16.0	1.4	3.2	123.1	7.54	148.8	68.2	16.3	3.4	7.9	126.3	7.62	152.3	71.3	16.6	6.2	14.3
				90	125.4	7.64	151.5	71.9	16.4	1.3	3.0	129.4	7.72	155.8	77.3	16.8	3.3	7.6	132.8	7.80	159.4	80.9	17.0	6.0	13.9
				50	91.8	7.22	116.4	38.6	12.7	1.6	3.7	94.7	7.29	119.6	41.5	13.0	3.8	8.8	97.2	7.37	122.4	43.4	13.2	6.8	15.7
				60	103.6	7.30	128.5	46.7	14.2	1.5	3.5	106.9	7.37	132.1	50.2	14.5	3.7	8.4	109.7	7.44	135.1	52.5	14.7	6.6	15.2
90	22.5	2.9	6.7	70	115.4	7.37	140.6	54.8	15.7	1.4	3.3	119.1	7.45	144.5	58.9	16.0	3.5	8.1	122.2	7.52	147.9	61.6	16.2	6.4	14.7
				80	121.4	7.54	147.2	63.2	16.1	1.4	3.2	125.3	7.62	151.3	68.0	16.4	3.4	7.9	128.5	7.70	154.8	71.1	16.7	6.2	14.3
				90	127.4	7.72	153.7	71.7	16.5	1.3	3.0	131.5	7.80	158.1	77.1	16.9	3.3	7.6	134.9	7.87	161.7	80.6	17.1	6.0	13.9
				50	93.0	7.29	117.9	38.1	12.8	1.6	3.7	97.2	7.37	122.3	41.4	13.2	3.8	8.8	99.1	7.44	124.5	43.3	13.3	6.8	15.7
				60	104.7	7.37	129.9	46.2	14.2	1.5	3.5	108.4	7.44	133.8	50.1	14.6	3.7	8.4	111.6	7.52	137.2	52.4	14.8	6.6	15.2
	30.0	5.5	12.7	70	116.4	7.45	141.8	54.3	15.6	1.4	3.3	119.7	7.52	145.3	58.7	15.9	3.5	8.1	124.0	7.60	149.9	61.5	16.3	6.4	14.7
				80	123.3	7.62	149.3	62.9	16.2	1.4	3.2	126.9	7.70	153.1	67.8	16.5	3.4	7.9	131.5	7.78	158.0	70.8	16.9	6.2	14.3
				90	130.2	7.80	156.8	71.6	16.7	1.3	3.0	134.1	7.87	160.9	77.0	17.0	3.3	7.6	139.0	7.95	166.2	80.2	17.5	6.0	13.9

Fig.5 - TWM120 Manufacture Data

1 Finding Headloss of TMW120 @ 80F and 18 GPM

2 Headloss of TMW120 @ 70F and 18GPM w/ Water

3 $$2.7+(18-15.0)\left(\frac{7.6-2.7}{22.5-15.0}\right)$$

$$=4.66$$

4 Headloss of TMW120 @ 90F and 18GPM w/ Water

5 $$2.3+(18-15.0)\left(\frac{6.7-2.3}{22.5-15.0}\right)$$

$$=4.06$$

6 Correction Factor for 15% Propylene-Glycol

7 $$k=1.152$$

−10 10

8 Headloss of TMW120 @ 80F and 18GPM w/ 15% Propylene-Glycol

9 $$\left(4.66+(80-70)\left(\frac{4.06-4.66}{90-70}\right)\right)\cdot k$$

$$=5.02272$$

Fig.6 - Calculate Headloss of TMW120

1 Estimating the K value Corresponding to the Piping Size for TMW120

2 Headloss for TMW120 @ 80F and 18GPM

3 $H = 5.02272$

−10 10

4 Velocity of 15% Propylene-Glycol in 2" SDR-11 2" Pipes @ 18GPM in ft^3/min

5 $$V = \frac{18 \cdot 0.133681}{0.020}$$

$V = 120.3129$

6 Acceleration due to Gravity in ft/min^2

7 $$g = 32.2\left(\frac{3600}{1}\right)$$

$g = 115920$

8 K value Corresponding to the Piping Size for TMW120

9 $$K = \frac{H}{V^2} 2g$$

$K = 80.445720612$

Fig.7 - Calculate K Value for TMW120

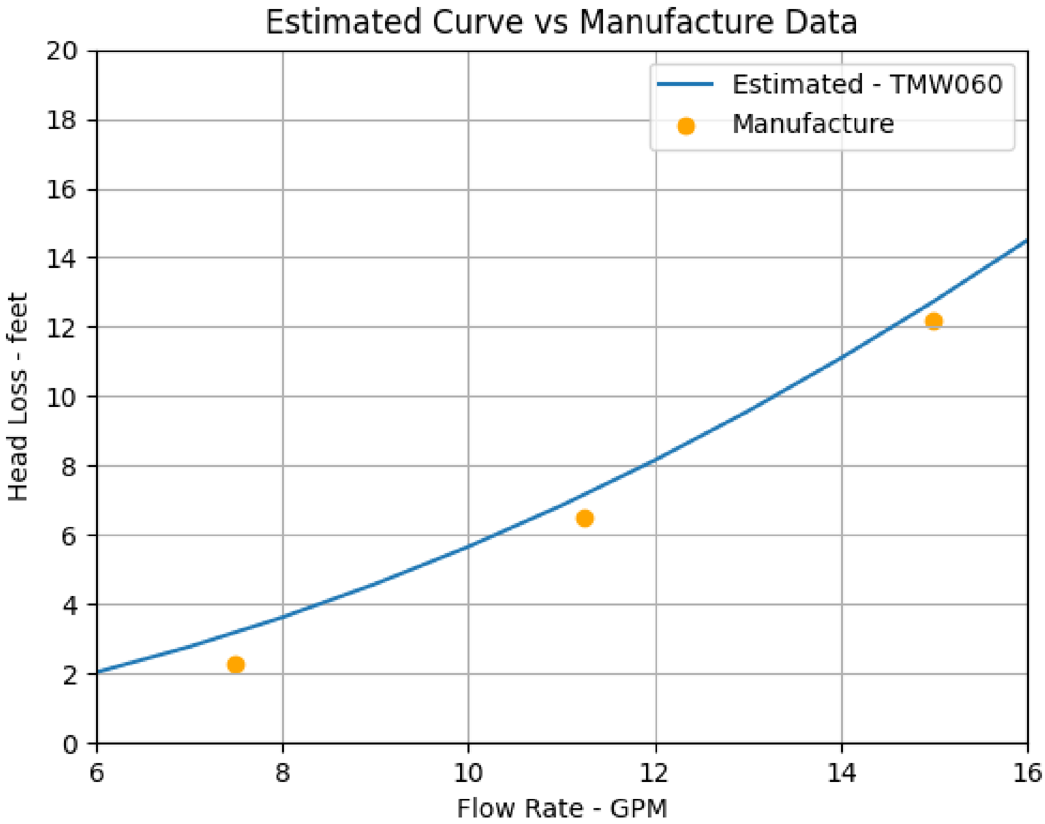


Fig.8 - TMW060 Estimated Curve vs Manufacture Data

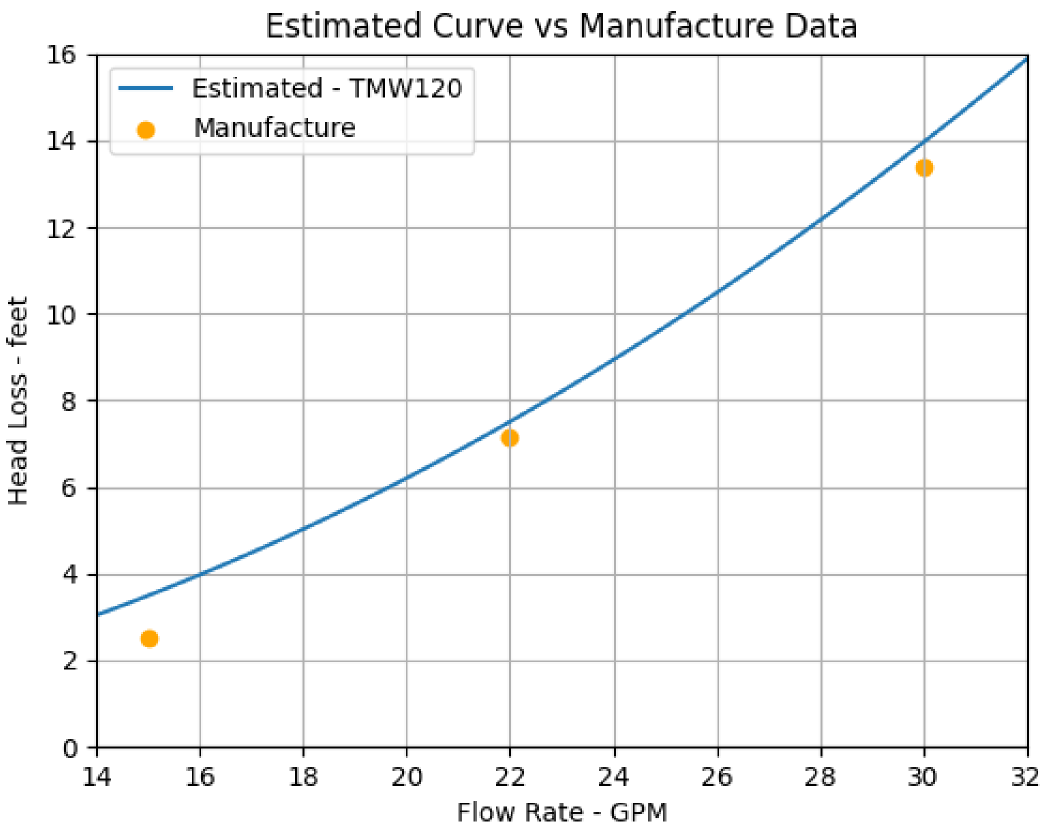


Fig.9 - TMW120 Estimated Curve vs Manufacture Data

3. System Design

The designer was tasked to design a piping system. Given the location and manufacturer data for the two heat pumps the design in Fig.10 was developed.

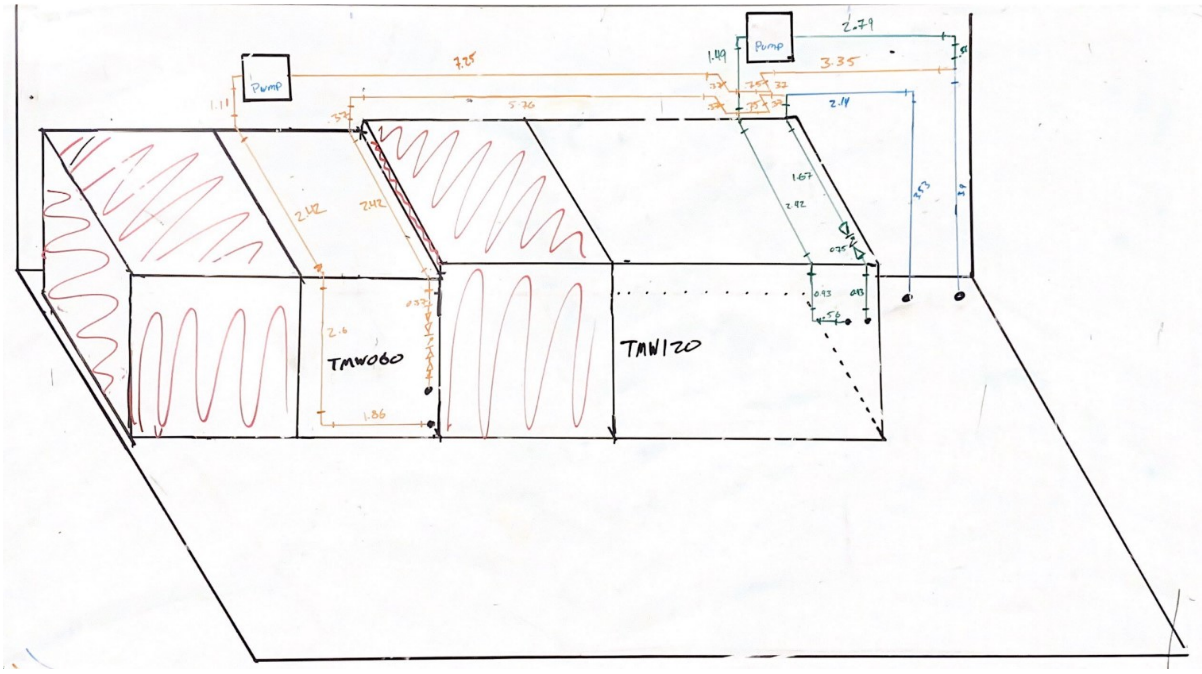


Fig.10 - Piping Design

4. Calculate System Headloss and Pump Selection

Question 4 asked the designed to size and choose a pump/pumps that would be suitable for the system. In order to size a pump, the headloss of the system and loop must be determined. The approach used in this report to calculate the headloss was to find the headloss of the straight piping (majorloss), then calculate the headloss of the fittings (minorloss), find calculate the headloss of the check valves, reducers, and expanders in the system, and then find the headloss of all equipment in the system.

Calculate Straight Piping Headloss

To calculate the majorloss the fluid velocity, pipe length, pipe diameter, and acceleration due to gravity. Given dimensions of the piping the Fig.11 and the fluid properties, it is possible to calculate all of these values. First the friction factor must be found. Using the method demonstrated in Fig.12. After determining the friction factor all the needed parameters have been found and the corresponding headloss was calculated. This method must be used to solve headloss at each flow rate individually. The calculation for the system's total major loss can be found in Fig.11 through Fig.18.

SDR 11

Nominal Size	Outer Diameter			Inside Diameter			Area	
in.	in.	ft	mm	in.	ft	mm	ft^2	m^2
3/4	1.050	0.0875	26.67	0.848	0.0707	21.54	0.0039	0.00036
1	1.315	0.1096	33.40	1.062	0.0885	26.96	0.0061	0.00057
1 1/4	1.660	0.1383	42.16	1.340	0.1117	34.03	0.0098	0.00091
1 1/2	1.900	0.1583	48.26	1.534	0.1278	38.96	0.0128	0.00119
2	2.375	0.1979	60.33	1.917	0.1598	48.70	0.0200	0.00186
2 1/2	2.875	0.2396	73.03	2.321	0.1934	58.96	0.0294	0.00273
3	3.500	0.2917	88.90	2.825	0.2355	71.77	0.0435	0.00405
3 1/2	4.000	0.3333	101.60	3.229	0.2691	82.02	0.0568	0.00528
4	4.500	0.3750	114.30	3.633	0.3027	92.27	0.0719	0.00669
5	5.563	0.4636	141.30	4.491	0.3742	114.07	0.1099	0.01022
6	6.625	0.5521	168.28	5.348	0.4457	135.85	0.1559	0.01449
8	8.625	0.7188	219.08	6.963	0.5802	176.86	0.2643	0.02457
10	10.750	0.8958	273.05	8.678	0.7232	220.43	0.4105	0.03816
12	12.750	1.0625	323.85	10.293	0.8577	261.44	0.5775	0.05368

Fig.11 -SDR11 Pipe Dimensions

1 Find Headloss of Indoor Piping and Fittings @ 27GPM

2 Headloss from Straight Piping @ 27GPM

3 $D = 0.1598$

−10 10

4 $V = \frac{9 \cdot 0.133681}{0.020}$

$V = 60.15645$

5 $v = 0.1365 \cdot \frac{1}{60}$

$v = 0.002275$

6 $R_e = \frac{VD}{v}$

$R_e = 4225.49481758$

7 Use Swamee and Jain Equation to find Friction Factor

8 $E = 0.020 \cdot \left(\frac{0.00328084}{1} \right)$

$E = 0.0000656168$

9 $f = \frac{0.25}{\log\left(\frac{E}{3.7 \cdot D} + \frac{5.74}{R_e^{0.9}} \right)^2}$

$f = 0.0403462688122$

Fig.12 - Calculate Friction Factor at 9 GPM

10

$$g = 32.2 \cdot \left(\frac{3600}{1} \right)$$

$g = 115920$

11

$$L = 31.44$$

−10 31.44

12

$$H_{major} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

$H_{major} = 0.123903955455$

Fig.13 - Calculate Headloss of Piping at 9 GPM

1 Find Headloss of Indoor Piping and Fittings @ 27GPM

2 Headloss from Straight Piping @ 27GPM

3 $D = 0.1598$

−10 10

4 $$V = \frac{18 \cdot 0.133681}{0.020}$$

$V = 120.3129$

5 $$v = 0.1365 \cdot \frac{1}{60}$$

$v = 0.002275$

6 $$R_e = \frac{VD}{v}$$

$R_e = 8450.98963516$

7 Use Swamee and Jain Equation to find Friction Factor

8 $$E = 0.020 \cdot \left(\frac{0.00328084}{1} \right)$$

$E = 0.0000656168$

9 $$f = \frac{0.25}{\log\left(\frac{E}{3.7 \cdot D} + \frac{5.74}{R_e^{0.9}} \right)^2}$$

$f = 0.0331183787062$

Fig.14 - Calculate Friction Factor at 18 GPM

10

$$g = 32.2 \cdot \left(\frac{3600}{1} \right)$$

$g = 115920$

11

$$L = 12.0$$

−10 12

12

$$H_{major} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

$H_{major} = 0.155277868569$

Fig.15 - Calculate Headloss of Piping at 18 GPM

1 Find Headloss of Indoor Piping and Fittings @ 27GPM

2 Headloss from Straight Piping @ 27GPM

3
$$D = 0.1598$$

−10 10

4
$$V = \frac{27 \cdot 0.133681}{0.020}$$

$$V = 180.46935$$

5
$$v = 0.1365 \cdot \frac{1}{60}$$

$$v = 0.002275$$

6
$$R_e = \frac{VD}{v}$$

$$R_e = 12676.4844527$$

7 Use Swamee and Jain Equation to find Friction Factor

8
$$E = 0.020 \cdot \left(\frac{0.00328084}{1} \right)$$

$$E = 0.0000656168$$

9
$$f = \frac{0.25}{\log\left(\frac{E}{3.7 \cdot D} + \frac{5.74}{R_e^{0.9}} \right)^2}$$

$$f = 0.0298445424686$$

Fig.16 - Calculate Friction Factor at 27 GPM

10

$$g = 32.2 \cdot \left(\frac{3600}{1} \right)$$

$g = 115920$

11

$L = 10.13$

−10 10.13

12

$$H_{major} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

$H_{major} = 0.265776229465$

Fig.17 - Calculate Headloss of Piping at 27 GPM

6

Find Headloss from external Piping

7

Acceleration Due to Gracity in ft/min^2

8

$$g = 32.2\left(\frac{3600}{1} \right)$$

$g = 115920$

9

Length of Piping in ft

10

$L = 400$

−10 400

11

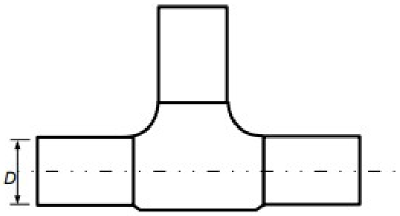
$$H = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

$H = 10.4946191299$

Fig.18 - Calculate Headloss of Outdoor Piping

Calculate Fitting Headloss

Next, the minorloss needs to be found. To find minorloss these parameters must be know: the K value corresponding to pipe diameter and fitting type, fluid velocity, and acceleration due to gravity. The K values can be found from literature and are presented in Fig.19. The approach to calculate minornloss at each individual flow rate in demonstrated in Fig.20 and then repeated in Fig.20 through Fig.23.

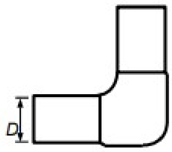


These tees connect three pipes of the same diameter.

K values depend only on if the flow goes straight ($K_{straight}$) or turns (K_{branch})

Nominal Size(inch)	3/4" IPS	1" IPS	1 1/4" IPS	1 1/2" IPS	2" IPS	3" IPS	4" IPS	6" IPS	8" IPS
$K_{straight}$	0.38	0.37	0.35	0.35	0.34	0.32	0.31	0.30	0.29
K_{branch}	1.15	1.10	1.06	1.04	1.01	0.96	0.93	0.90	0.88

Elbows



3/4" IPS	1" IPS	1 1/4" IPS	1 1/2" IPS	2" IPS	3" IPS	4" IPS	6" IPS	8" IPS
0.57	0.55	0.53	0.52	0.50	0.48	0.47	0.45	0.44

Fig.19 - SDR11 Fitting K Values

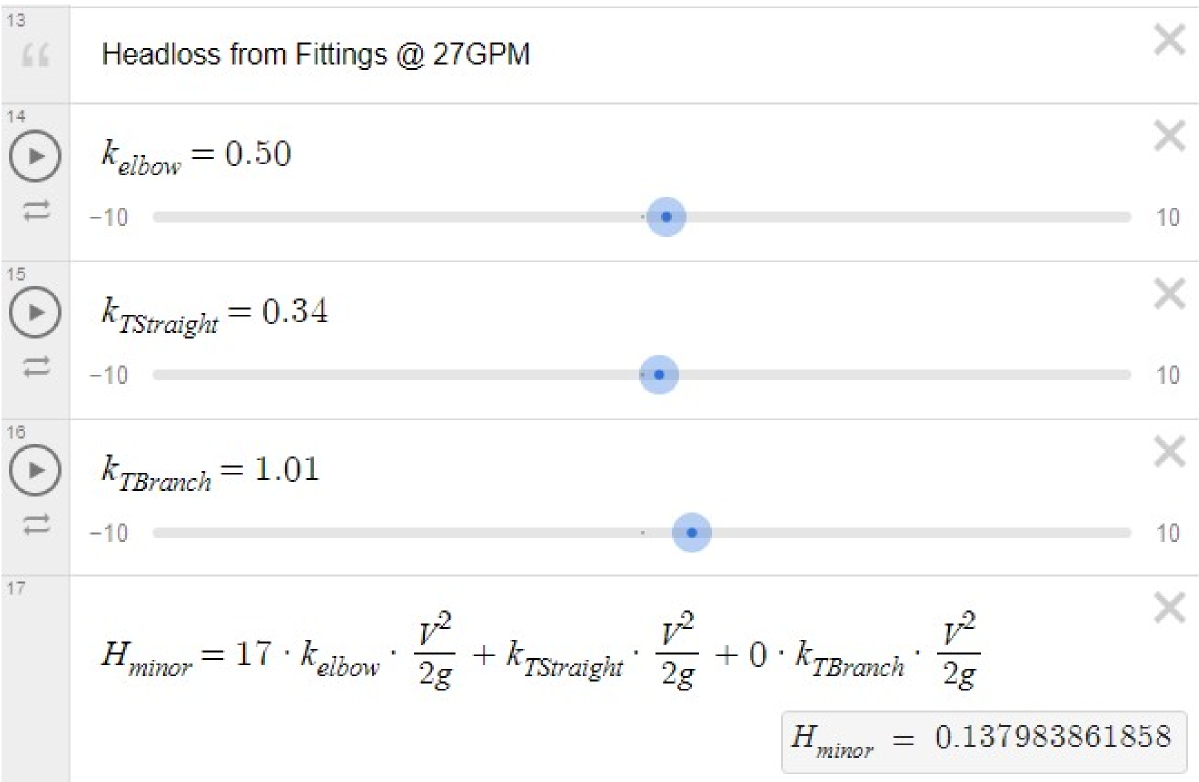


Fig.20 - Calculate Headloss of Fittings at 9 GPM

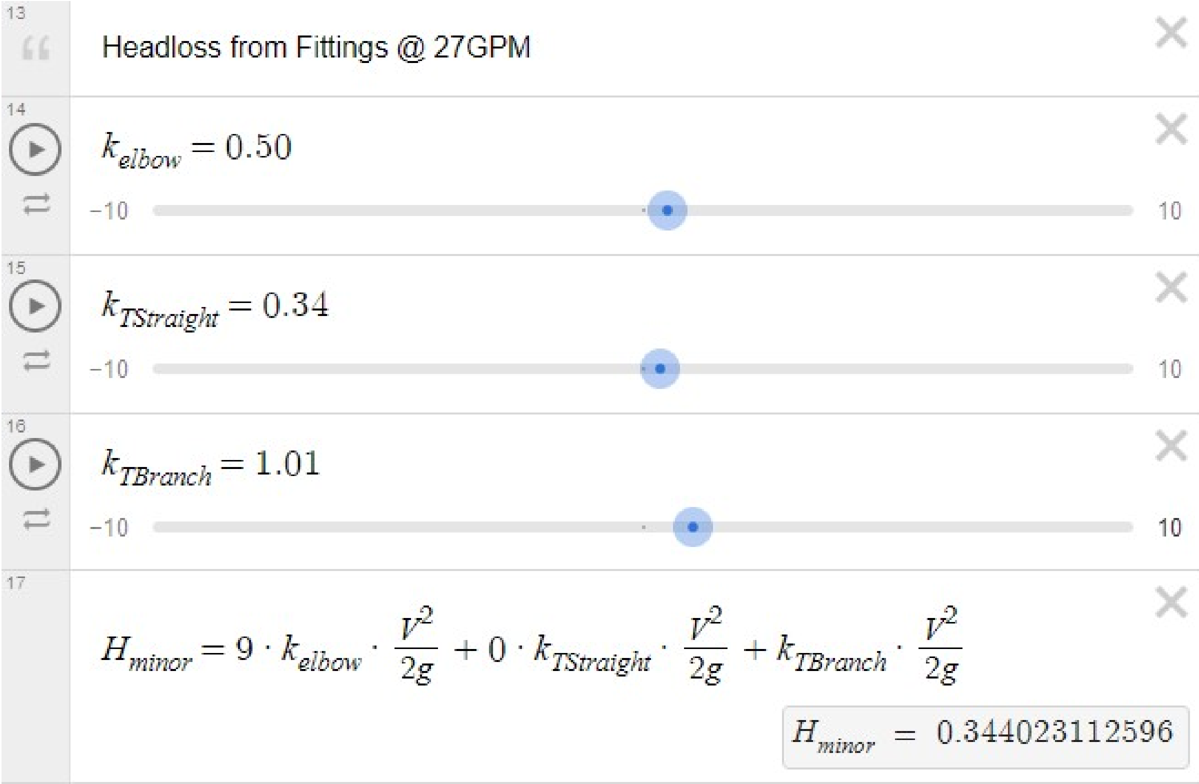


Fig.21 - Calculate Headloss of Fittings at 18 GPM

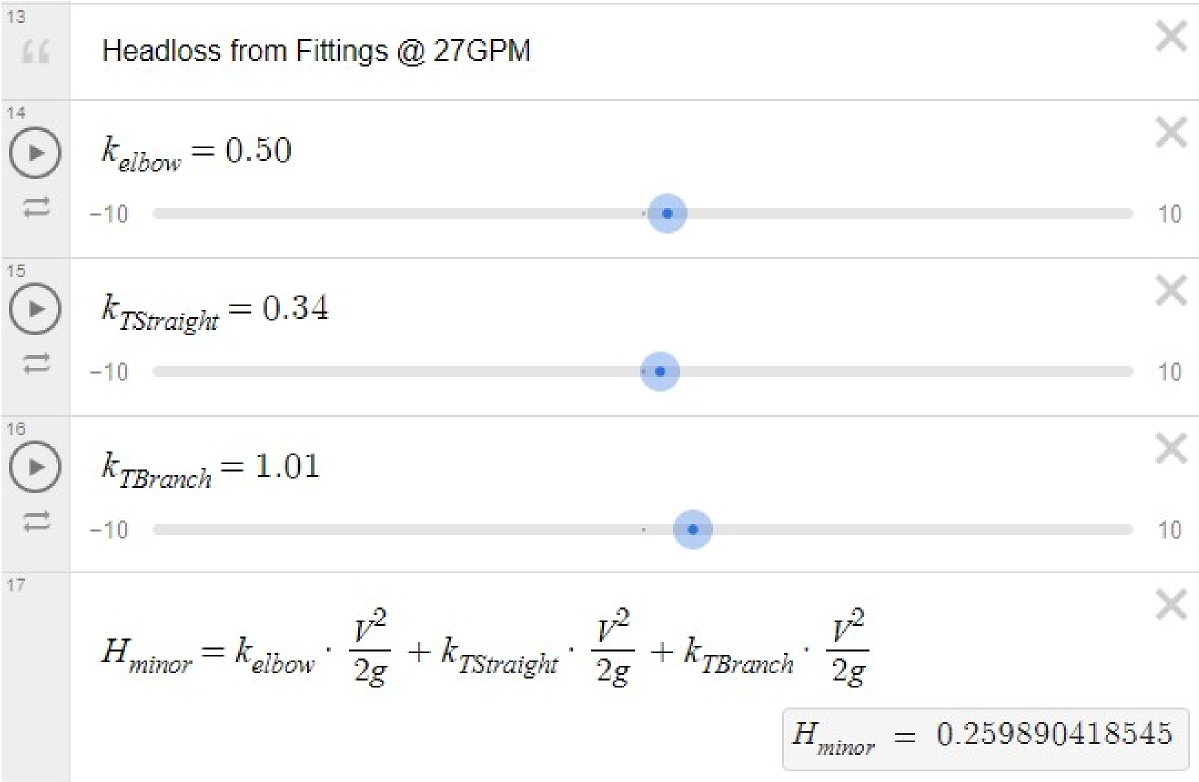


Fig.22 - Calculate Headloss of Fittings at 27 GPM

1 Calculate Headloss from External Piping, Fittings, and Equipment

2 Calculate Headloss from External Fittings

3 There are 8x 2" Elbows (Similar to HW2B)

4 $k = 0.50$

−10 10

5 Velocity of 15% Propylene-Glycol @ 80F and 27GPM in ft/min

6 $$V = \frac{27 \cdot 0.133681}{0.020}$$

$V = 180.46935$

7 Acceleration Due to Gravity in ft/min^2

8 $$g = 32.2 \cdot \left(\frac{3600}{1} \right)$$

$g = 115920$

9 Headloss from 8x 2" Elbows

10 $$H = 8 \cdot \left(k \cdot \frac{V^2}{2g} \right)$$

$H = 0.561925229286$

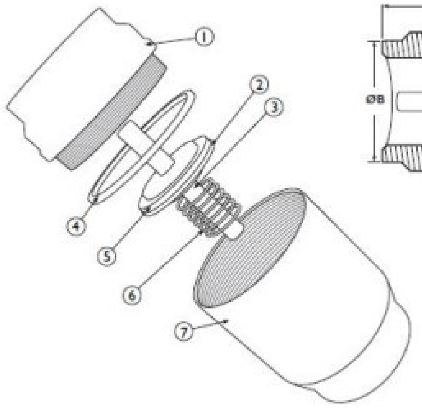
Fig.23 - Calculate Headloss of Outdoor Fittings

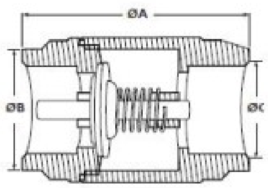
Calculate Headloss of Check Valves, Reducers, and Expanders

While check valves, reducers, and expanders are technically fittings, for the purpose of this report it made more sense to calculate them apart from minorloss. Literature states that the K value for a check value is 100 times greater than the friction factor, however this left many question. Therefor, the designer decided to source their own check valves. Quickly upon searching, it became clear that there are almost no check valves that are the same 2" diameter as the piping and have a low enough cracking pressure to be a viable option. Because of this the designer chose two check different check valves, one ½" valve that will be installed inline with 9 GPM flow, and one 1" valve that will be installed inline with the 18 GPM flow. The dimensions for the selected check valves are presented in Fig.25. Once the check valves were selected the headloss was found using the chart in Fig.26.

STAYFLOW

VCSIL-ST1VXT Silent Check Valve
Thread Style, Class 300, SS Body, SS Disc, Viton Seat





Design Notes:
1. Size range: 3/8" ~ 3"
2. ANSI Class 300
3. Low cracking pressure
4. Minimal head loss
5. Low pressure drop
6. Spring assisted design
7. Long stem for smooth closure
8. Viton Seat for long service life

BILL OF MATERIALS		
NO.	PART	MATERIAL
1	Cap	ASTM A351 Gr. CF8M Stainless Steel
2	Disc	Stainless Steel 18-8
3	Stem	ASTM A351 Gr. CF8M Stainless Steel
4	Gasket	PTFE
5	Seat	Viton
6	Spring	Type 316 Stainless Steel
7	Body	ASTM A351 Gr. CF8M Stainless Steel

DIMENSIONS & PERFORMANCE DATA									
SIZE	3/8	1/2	3/4	1	1.25	1.5	2	2.5	3
A (in)	2.086	2.204	2.480	2.913	3.188	3.582	3.818	4.660	5.500
B (in)	0.905	1.181	1.620	1.878	2.165	2.775	3.228	4.312	4.900
C (in)	0.669	0.826	1.023	1.259	1.614	1.850	2.322	2.625	3.250
WT (lb)	0.3	0.4	0.5	1.0	1.5	2.5	3.5	6.0	8.5
Cx	6	7	14	20	40	40	80	110	162

Fig.25 - Check Valve Dimensions

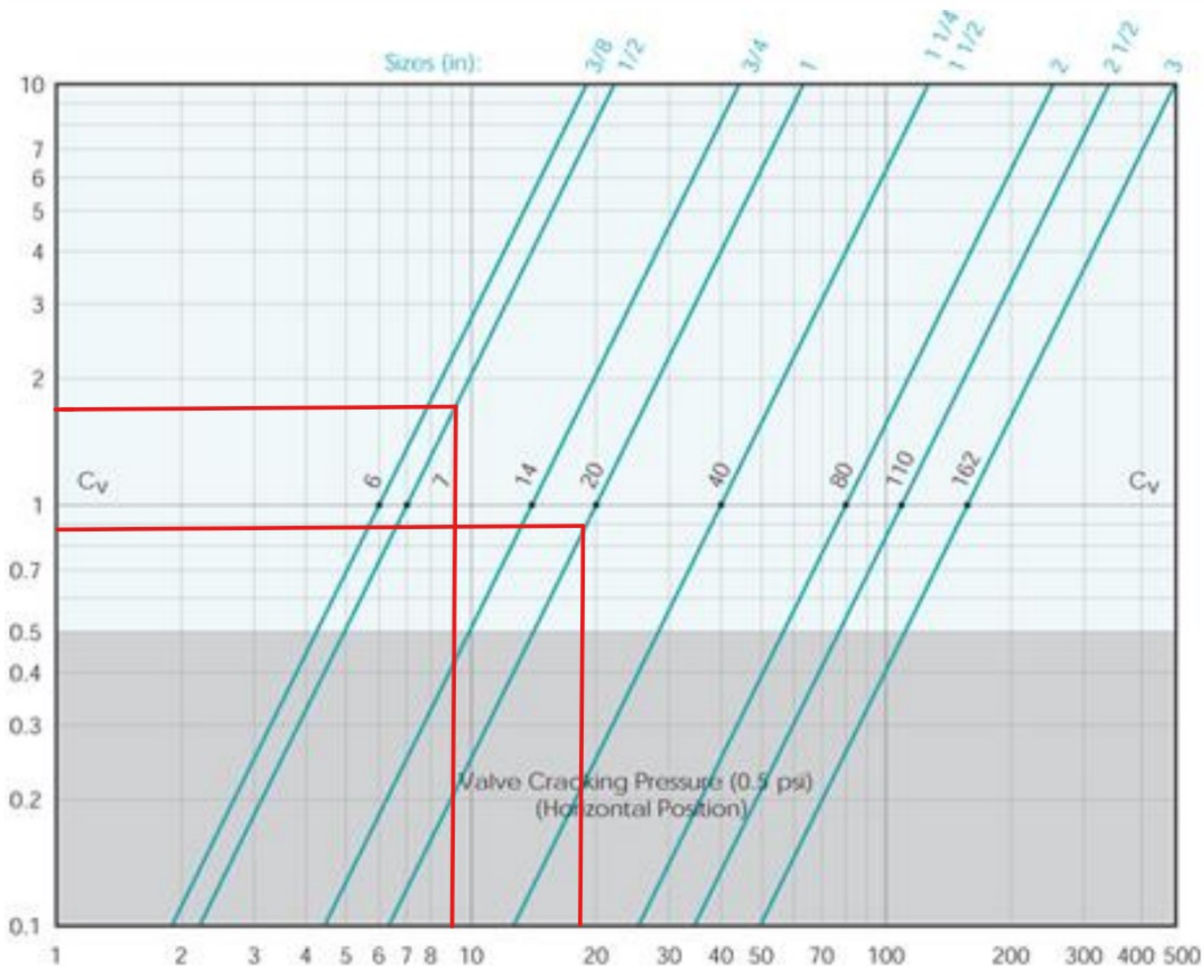
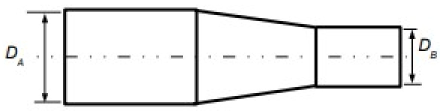


Fig.26 - Determine Check Valve Headloss

As reducers and expanders fittings, the K value corresponding to pipe diameter and fitting type, fluid velocity, and acceleration due to gravity. The K values can be found from literature and are presented in Fig.27. The approach to calculate headloss from reducers and expander is demonstrated in Fig.28 and then repeated in Fig.28 through Fig.31.

Reducer/Expander



Reducer/Expander *K* values have been determined for commercially available (from one manufacturer) HDPE "Butt Reducers" The values given in the table below are for SDR-11 piping. The *K* value depends on the direction of flow and the pipe diameter with which you wish to use the *K* value. The diameter D_A always refers to the larger pipe.

	IPS x IPS	1" x 1/2"	1" x 3/4"	1-1/4" x 3/4"	1-1/4" x 1"	1-1/2" x 3/4"	1-1/2" x 1"	1-1/2" x 1-1/4"	2" x 1"
				Reducers					
Based on small pipe I.D.	K_B	0.08	0.02	0.09	0.03	0.20	0.11	0.02	0.26
Based on large pipe I.D.	K_A	0.56	0.06	0.56	0.07	2.14	0.47	0.04	2.75
				Expanders					
Based on small pipe I.D.	K_B	0.16	0.03	0.17	0.03	0.45	0.18	0.02	0.48
Based on large pipe I.D.	K_A	1.13	0.07	1.09	0.08	4.84	0.79	0.03	5.12

Fig.27 - SDR11 Reducer and Expander K Values

1

Finding the Headloss of Reducers from 2" to 1/2" @ 9GPM

2

$$g = 32.2\left(\frac{3600}{1}\right)$$

$g = 115920$

3

$$k_1 = 2.75$$

−10 10

4

$$V_1 = \frac{9 \cdot 0.133681}{0.0200}$$

$V_1 = 60.15645$

5

$$k_2 = 0.56$$

−10 10

6

$$V_2 = \frac{9 \cdot 0.133681}{0.0061}$$

$V_2 = 197.234262295$

7

$$H_1 = k_1 \cdot \frac{V_1^2}{2g} + k_2 \cdot \frac{V_2^2}{2g}$$

$H_1 = 0.136889467631$

Fig.28 - Calculate Reducer Headloss at 9 GPM

1 Finding the Headloss of Reducers from 2" to 1" @ 18GPM

2 $$g = 32.2\left(\frac{3600}{1}\right)$$

$g = 115920$

3 $$k = 2.75$$

−10 10

4 $$V = \frac{18 \cdot 0.133681}{0.0200}$$

$V = 120.3129$

5 $$H_1 = k \cdot \frac{V^2}{2g}$$

$H_1 = 0.171699375615$

Fig.29 - Calculate Reducer Headloss at 18 GPM

7 Finding Headloss of Expanders from 1/2" to 2" @ 9GPM

8 $$g = 32.2\left(\frac{3600}{1}\right)$$

$g = 115920$

9 $$k_3 = 0.16$$

−10 10

10 $$V_3 = \frac{9 \cdot 0.133681}{0.0061}$$

$V_3 = 197.234262295$

11 $$k_4 = 0.48$$

−10 10

12 $$V_4 = \frac{9 \cdot 0.133681}{0.0200}$$

$V_4 = 60.15645$

13 $$H_2 = k_3 \cdot \frac{V_3^2}{2g} + k_4 \cdot \frac{V_4^2}{2g}$$

$H_2 = 0.0343393717411$

Fig.30 - Calculate Expander Headloss at 9 GPM

Finding the Headloss of Expander from 2" to 1" @ 18GPM

$$g = 32.2\left(\frac{3600}{1}\right)$$

$g = 115920$

$$k = 0.48$$

−10 10

$$V = \frac{18 \cdot 0.133681}{0.0061}$$

$V = 394.46852459$

$$H = k \cdot \frac{V^2}{2g}$$

$H = 0.322164424208$

Fig.31 - Calculate Expander Headloss at 18 GPM.jpg

Calculate Headloss of Equipment

Lastly the headloss from equipment such as the head pumps and heat exchangers need to be accounted for. The headloss for the heat pumps has been calculated above. The headloss for the heat exchangers can be calculated using the relationship provided by the literature. This calculation is presented in Fig.32.

Calculate Headloss from Heat Exchangers from provided equation @ 27 GPM

$$H = 0.0066z^2 - 0.12z + 5.6053$$

$H = 7.1767$

$$z = 27$$

−10 27

Fig.32 - Calculate Headloss of Heat Exchangers

Pump Selection/Analysis

The total system head can now be calculated by adding everything together and it is possible to size a pump. Fig.33 show the design point for pumps in series and single pump at 9 GPM and 18 GPM. The horizontal red line represents the design point for single pumps, and the horizontal blue line represents the design point for two pumps in series.

The figure clearly shows that using a single pump to accommodate for the headloss at the design flowrate will not be enough. However, in series each pump will only be accountable for half of the head. The figure shows that there are many pump combinations that exceed the requirements. Using Fig.33, 2 TACO-0014 circulator pumps in series were selected to pump fluid through the TMW060 loop, and 2 TACO-0013 circulator pumps in series were selected to pump fluid through the TMW120 loop.

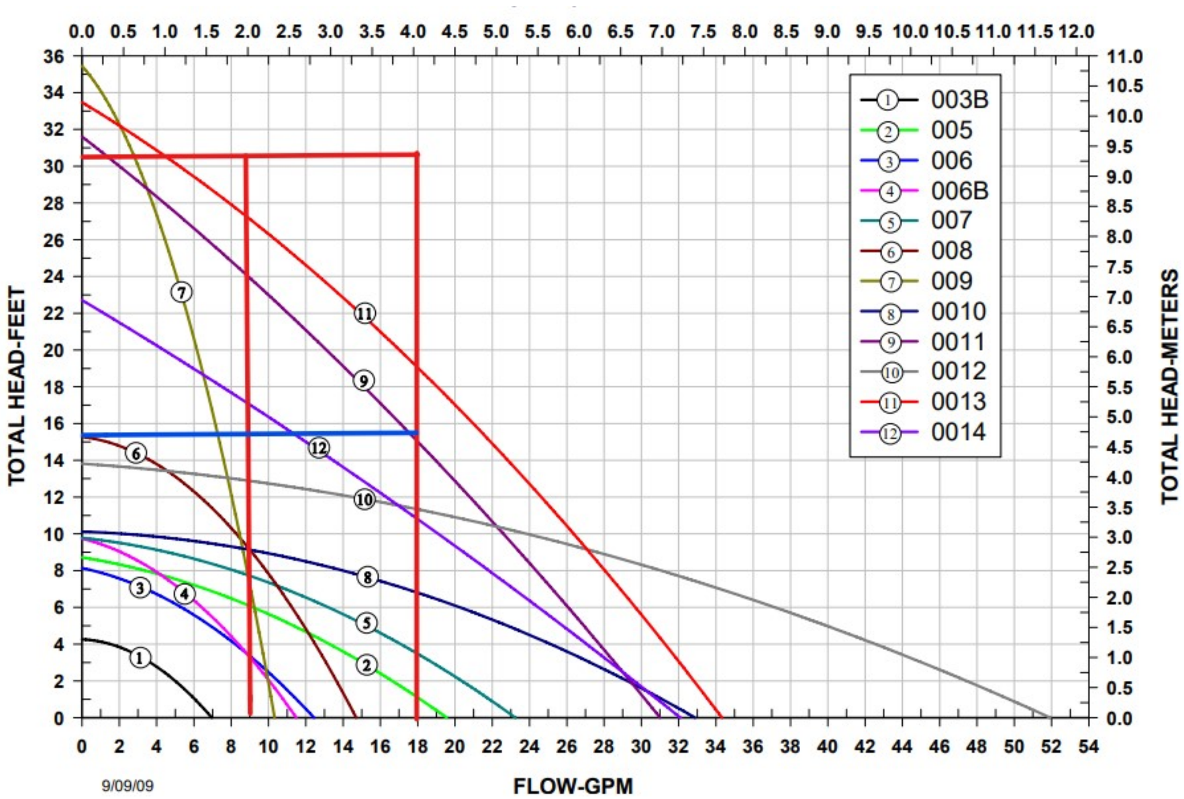


Fig.33 - Pump Requirements in Series

Using a python script, pump curves for a single TACO-0013, 2 TACO-0013 pumps in series, a singleTACO-0014, and 2 TACO-0014 in series were plotted. The required design points were also plotted as well as the actual operating point and system curves . By comparing the actual operating point headloss to the design point headloss it was confirmed that the pumps in series will work well.

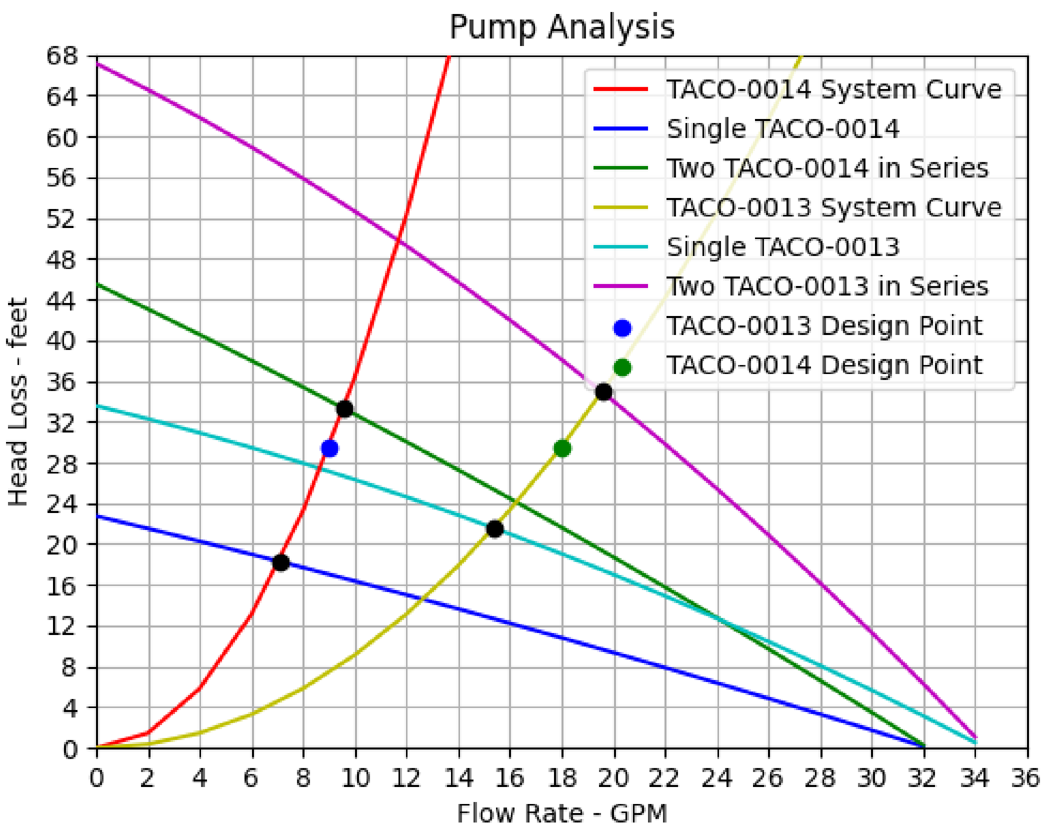


Fig.34 - Pump Analysis

5. Plotting Pump Curves

Similar to question 2, it is important for designers to validate their models against the manufacture data. A comparison between the plotted/calculated pump curve and the manufacture data is found in Fig.35

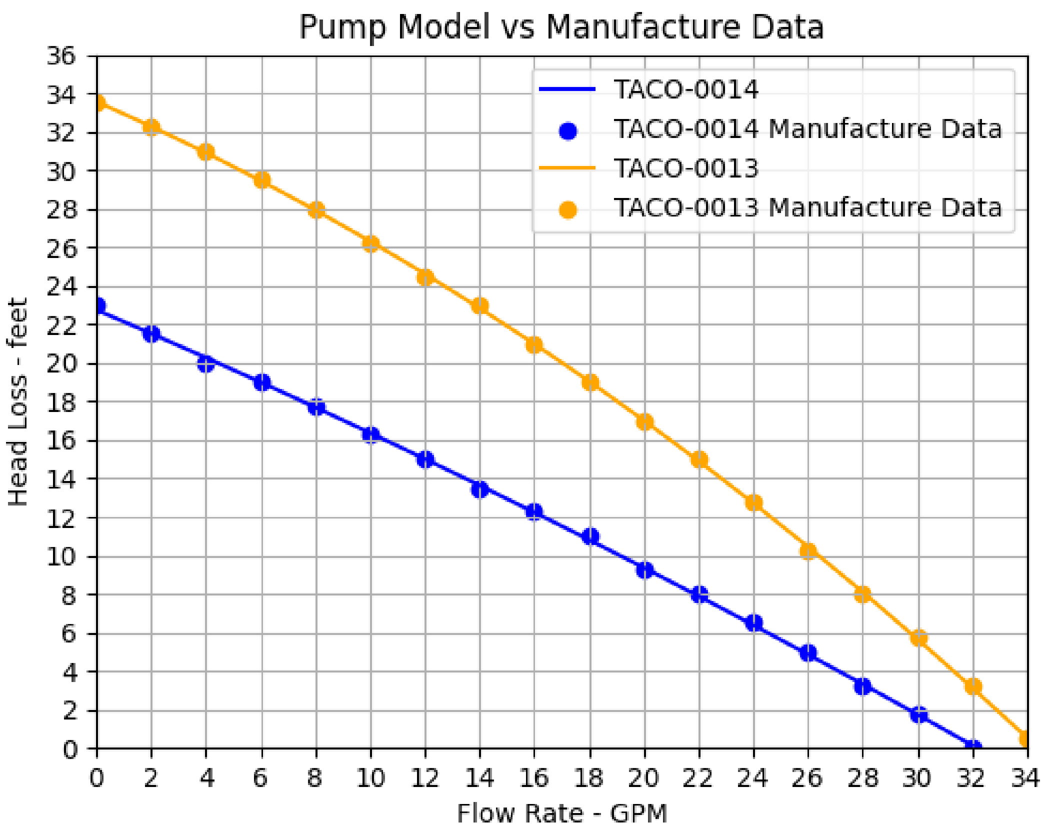


Fig.35 - Pump Model vs Manufacture Data

6. P&ID and Headloss Summary

Below is a P&ID clarifying any design configurations. The headloss totals and the number of fittings for each loop are displayed in Fig.36 through Fig.39.

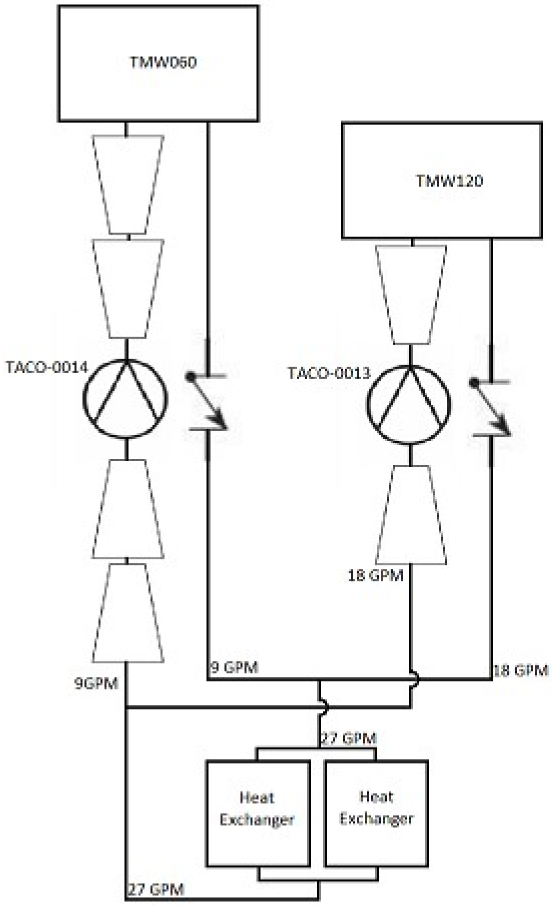


Fig.36 - P&ID

Headloss From Inside Components (Operating @ 9GPM)		
Source	Quantity	Headloss
Straight Piping	31.44	0.123903955
Elbows	17	0.13267679
Tee Straight	1	0.005307072
Reducer	2	0.136889468
Expander	2	0.034339372
Check Valve	1	1.8
Heat Pump	1	4.58496
	TOTAL	6.818076657
	PUMP HEAD	25.57698766

Fig.37 - Headloss for Componenets Operating at 9 GPM

Headloss From Inside Components (Operating @ 18GPM)		
Source	Quantity	Headloss
Straight Piping	12	0.155277869
Elbows	9	0.280962615
Tee Branch	1	0.063060498
Reducer	1	0.171699376
Expander	1	0.322164424
Check Valve	1	0.9
Heat Pump	1	5.02272
	TOTAL	6.915884781
	PUMP HEAD	25.67479579

Fig.38 - Headloss for Componenets Operating at 18 GPM

Headloss From Outside Componets (Operating @ 27GPM)		
Source	Quantity	Headloss
Straight Piping	400	10.49461913
Elbows	8	0.561925229
Heat Exchanger	1	7.1767
	TOTAL	18.23324436

Headloss From Inside Components (Operating @ 27GPM)		
Source	Quantity	Headloss
Straight Piping	10.13	0.265776229
Elbows	1	0.070240654
Tee Straight	1	0.047763644
Tee Branch	1	0.14188612
	TOTAL	0.525666648

Fig.39 - Headloss for Componenets Operating at 27 GPM

7. Automating Headloss Calculations

Question 7 asked the designer to automate the work that was done in question 4. This was accomplished using the two python scripts that are displayed below. Headloss calculations have been reduced to one function, `headloss(diameter:float,flow_rate:float,length:float,heat_pump:bool=False,heat_pump_loss:float=0,heat_exchanger:bool=False,etc_loss:float=0,elbows:int=0,tstraight:int=0,tbranch:int=0)`. `diameter` is the diameter of the pipe, `flow_rate` is the flow rate of that section of piping, `length` is the length of straight pipe, `heat_pump` is a Boolean that determines if there is heat pump in that section of piping, `heat_pump_loss` is the headloss that was calculated elsewhere, `heat_exchanger` is a Boolean that determines if there is a heat exchanger in the loop, `etc_loss` accounts for any loss besides major, minor, or equipment loss (ie. Check valves, reducers and expanders), `elbows` is the number of elbows in the loop, `tstraight` is the number of Tee-Straight fittings in the loop, and `tbranch` is the number of Tee-Branch fittings in the loop.

```
import numpy as np
from simulation_pump_curve import plot_simulation

def
calc_headloss(diameter:float,flow_rate:float,length:float,heat_pump:bool=False,hea
t_pump_loss:float=0,heat_exchanger:bool=False,etc_loss:float=0,elbows:int=0,tstrai
ght:int=0,tbranch:int=0):

    k_tstraight = 0.34
    k_tbranch = 1.01
    k_elbow = 0.50
    g = 32.2*3600 # ft/min^2

    # FUNCTION TO CALCULATE MAJOR LOSS USING PIPE DIAMETER, FLOW RATE, LENGTH OF
PIPE, AND VELOCITY OF FLUID
    def
calc_major_loss(diameter:float,flow_rate:float,length:float,velocity:float):

        # FUNCTION TO FIND REYNOLDS NUMBER FOR 15% PROPYLENE-GLYCOL (Kinematic-
Viscosity = 0.1365/60)
        def calc_reynolds_number(diameter:float,velocity:float):
            reynolds_number = velocity * diameter / (0.1365/60)
            return reynolds_number

        # FUNCTION TO FIND FRICTION FACTOR FOR 2" SDR11 PIPING
        def calc_friction_factor(diameter:float,velocity:float):
            relative_roughness = ((np.pi/4)*diameter**2) * 0.00328084
            reynolds_number = calc_reynolds_number(diameter,velocity)
            friction_factor = 0.25/(np.log((relative_roughness/(3.7*diameter))+
(5.74/(reynolds_number**2)))**2)
            return friction_factor

        friction_factor = calc_friction_factor(diameter,velocity)
        headloss = friction_factor * (length/diameter) * (velocity**2 / (2*g))
        return headloss

    def calc_minor_loss(velocity:float,elbows:int,tstraight:int,tbranch:int):
        h1 = elbows * k_elbow * velocity**2 / (2*g)
        h2 = tstraight * k_tstraight * velocity**2 / (2*g)
        h3 = tbranch * k_tbranch * velocity**2 / (2*g)
        headloss = h1 + h2 + h3
        return headloss

    def calc_heat_exchanger_loss(flow_rate):
        headloss = 0.0066*flow_rate**2 - 0.12*flow_rate + 5.6053
        return headloss

    velocity = (flow_rate*0.133681)/((np.pi/4)*(diameter**2))
    major_loss = calc_major_loss(diameter,flow_rate,length,velocity)
    minor_loss = calc_minor_loss(velocity,elbows,tstraight,tbranch)
```

```
    if heat_exchanger == True and heat_pump ==True:
        equipment_loss = calc_heat_exchanger_loss(flow_rate) + heat_pump_loss
    elif heat_exchanger == False and heat_pump == True:
        equipment_loss = heat_pump_loss
    elif heat_exchanger == True and heat_pump == False:
        equipment_loss = calc_heat_exchanger_loss(flow_rate)

    headloss = major_loss + minor_loss + equipment_loss + etc_loss
    return headloss

def calc_simulation_headloss(situation:int=0):
    diameter = 0.1598
    tmw120_loss = 5.02272 # FOUND ON SUBMITAL SHEETS
    tmw060_loss = 4.58496 # FOUND ON SUBMITAL SHEETS

    if situation == 0: # SITUATION 0 INDICATES BOTH HEAT PUMPS IN OPERATION
        etc_loss2 = 1.3938638 # ETC HEADLOSS IS THE HEADLOSS FROM THE CHECK VALVE
AND REDUCERS
        etc_loss3 = 1.971228839 # ETC HEADLOSS IS THE HEADLOSS FROM THE CHECK
VALVE, EXPANDERS, AND REDUCERS
        h1 = calc_headloss(diameter,27,410.13,False,0,True,0,9,1,1) # H1 IS THE
HEADLOSS FROM ALL PIPING/EQUIPMENT THAT OPPERATES AT 27 GPM
        h2 = calc_headloss(diameter,18,12,True,tmw120_loss,False,etc_loss2,9,0,1)
# H2 IS THE HEADLOSS FROM ALL PIPING/EQUIPMENT THAT OPPERATES AT 18 GPM
        h3 =
calc_headloss(diameter,9,31.44,True,tmw060_loss,False,etc_loss3,17,1,0) # H3 IS
THE HEADLOSS FROM ALL PIPING/EQUIPMENT THAT OPPERATES AT 9 GPM
        headloss = (h1 + h2 + h3) * 1.15 # TOTAL HEADLOSS WITH A 15% FACTOR OF
SAFETY
        return headloss
    elif situation == 1: # SITUATION 1 INDICATES ONLY THE TMW060 HEAT PUMPS IS IN
OPERATION
        etc_loss2 = 1.3938638 # ETC HEADLOSS IS THE HEADLOSS FROM THE CHECK VALVE,
EXPANDERS, AND REDUCERS
        h1 = calc_headloss(diameter,9,410.13,False,0,True,0,9,1,1) # H1 IS THE
HEADLOSS FROM ALL PIPING/EQUIPMENT THAT OPPERATES AT 27 GPM
        h2 =
calc_headloss(diameter,9,31.44,True,tmw060_loss,False,etc_loss2,17,1,0) # H3 IS
THE HEADLOSS FROM ALL PIPING/EQUIPMENT THAT OPPERATES AT 9 GPM
        headloss = (h1 + h2) * 1.15 # TOTAL HEADLOSS WITH A 15% FACTOR OF SAFETY
        return headloss
    elif situation == 2: # SITUATION 2 INDICATES ONLY THE TMW120 HEAT PUMPS IS IN
OPERATION
        etc_loss2 = 1.971228839 # ETC HEADLOSS IS THE HEADLOSS FROM THE CHECK
VALVE, EXPANDERS, AND REDUCERS
        h1 = calc_headloss(diameter,18,410.13,False,0,True,0,9,1,1) # H1 IS THE
HEADLOSS FROM ALL PIPING/EQUIPMENT THAT OPPERATES AT 27 GPM
        h2 = calc_headloss(diameter,18,12,True,tmw120_loss,False,etc_loss2,9,0,1)
# H2 IS THE HEADLOSS FROM ALL PIPING/EQUIPMENT THAT OPPERATES AT 18 GPM
        headloss = (h1 + h2 ) * 1.15 # TOTAL HEADLOSS WITH A 15% FACTOR OF SAFETY
```

```
        return headloss
    else:
        print('no')

def main():
    situation0_headloss = (calc_simulation_headloss(0)) # HEADLOSS FOR SITUATION 0
RETURNED 25.93365260965075 ft
    situation1_headloss = (calc_simulation_headloss(1)) # HEADLOSS FOR SITUATION 1
RETURNED 13.105649389716984 ft
    situation2_headloss = (calc_simulation_headloss(2)) # HEADLOSS FOR SITUATION 2
RETURNED 15.844505127782224 ft

    head_loss_TACO0014 =
[23,21.5,20,19,17.75,16.25,15,13.5,12.25,11,9.25,8,6.5,5,3.25,1.75,0]
    for i in range(len(head_loss_TACO0014)):
        head_loss_TACO0014[i] = head_loss_TACO0014[i] * 2
    head_loss_TACO0013 =
[33.5,32.25,31,29.5,28,26.25,24.5,23,21,19,17,15,12.75,10.25,8,5.75,3.25,0.5]
    for i in range(len(head_loss_TACO0013)):
        head_loss_TACO0013[i] = head_loss_TACO0013[i] * 2
    plot_simulation(head_loss_TACO0014,(situation1_headloss,9),'Pump Analysis for
only TMW060 Opperating','TMW060 Only Pump Curve.png')
    plot_simulation(head_loss_TACO0013,(situation2_headloss,18),'Pump Analysis for
only TMW120 Opperating','TMW120 Only Pump Curve.png')
main()


import matplotlib.pyplot as plt
from numpy import linspace, poly1d, polyfit
from scipy.optimize import fsolve

def calc_pump_curve(head_loss:list[float],flow_rates:list[float]):
    # FIND EQUATION FOR PUMP CURVE
    pump_curve = poly1d(polyfit(x=flow_rates,y=head_loss,deg=2))
    return pump_curve

def
calc_system_curve(flow_rates:list[float],total_head_loss:float,flow_rate:float):

    # FIND EQUATION FOR SYSTEM CURVE
    k = total_head_loss / (flow_rate**2)
    system_head_loss = []
    for i in range(len(flow_rates)):
        head = k*((flow_rates[i])**2)
        system_head_loss.append(head)
    system_curve = poly1d(polyfit(x=flow_rates,y=system_head_loss,deg=2))
    return system_curve

def calc_aop(pump_curve,system_curve):
    # FIND INTERSECTION OF PUMP AND SYSTEM TO FIND AOP
    def find_intersection(func1,func2,x0:int=0):
```

```
        return fsolve(lambda x: func1(x)-func2(x),x0)
    x_intersect = find_intersection(pump_curve,system_curve)
    return x_intersect

def
plot(head_loss:list[float],pump_curve,system_curve,aop:float,design_point:tuple=
(0,0),title:str='',file:str='simulation.png'):
    plt.plot(head_loss,system_curve(head_loss),zorder=4,color='b') # PLOT SYSTEM
CURVE
    plt.plot(head_loss,pump_curve(head_loss),zorder=3,color='g') # PLOT PUMP CURVE
    plt.scatter(aop,system_curve(aop),zorder=5,color='r') # PLOT AOP
    plt.scatter(design_point[0],design_point[1],zorder=5,color='k')# PLOT DESIGN
POINT

    # MAKE THE PLOT LOOK NICE
    plt.title(title)
    plt.legend(['System Curve','Pump Curve','Actual Opperating Point','Design
Point'],loc="upper right")
    plt.xlabel('Flow Rate - GPM')
    plt.ylabel('Headloss - ft')
    plt.margins(x=0,y=0)
    plt.grid(which="major")
    x_intercept = 0
    plt.ylim(bottom=0,top=pump_curve(0)+4)
    while pump_curve(x_intercept) > 0:
        x_intercept = x_intercept +  1
    plt.xlim(left=0,right=x_intercept+4)

    # SAVE FIGURE
    plt.savefig(file)

def
plot_simulation(head_loss:list[float],design_point,title:str='',file:str='simulati
on.png'):
    flow_rates = linspace(0, (len(head_loss)-1)*2, len(head_loss))
    pump_curve = calc_pump_curve(head_loss,flow_rates)
    system_curve = calc_system_curve(flow_rates,design_point[1],design_point[0])
    aop = calc_aop(pump_curve,system_curve)
    plot(head_loss,pump_curve,system_curve,aop,design_point,title,file)
    plt.clf()
```

Fig.40 shows the design point when only the TMW060 is operating. It is clear that the actual operating point has enough headloss to pump the needed headloss at the design point. The same conclusion can be made when only the TMW120 is operating. This can be concluded based on Fig.41.

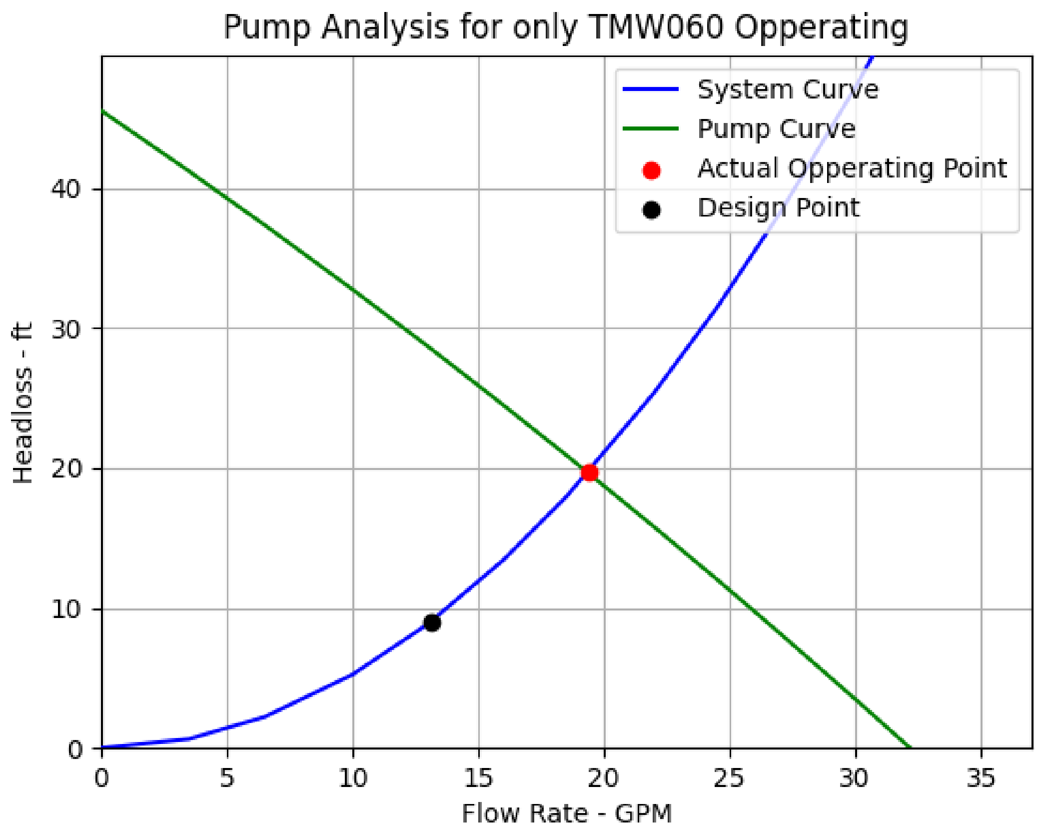


Fig.40 - TMW060 Only Pump Curve

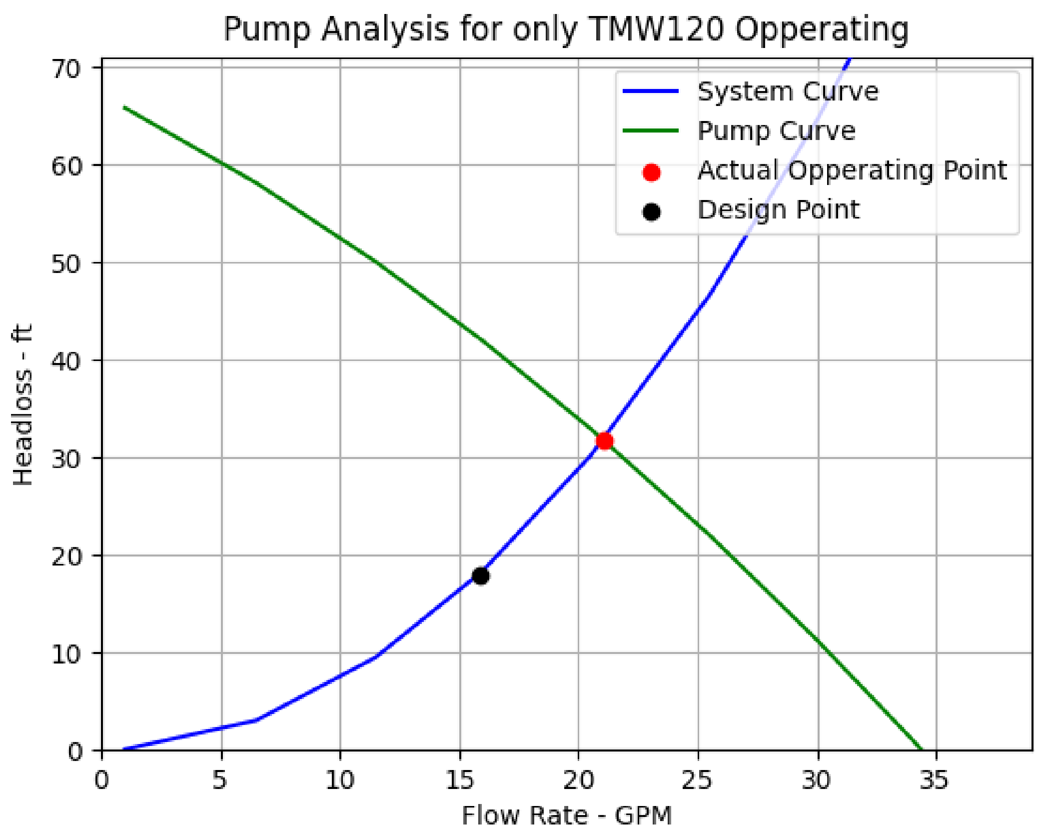


Fig.41 - TMW120 Only Pump Curve

8. Power Consumption Analysis

Question 8 required the calculation of system power consumption in different situations. The first thing that needs to be found is the power/electrical data for the heat pump and two pumps' models. This data is shown in Fig.42, Fig.43, and Fig.44.
To find the power the voltage and current need to be multiplied, this is done for the pumps and heat pump. Then the power of both pumps and the heat pump are added together to find the power per hour. Then the power per hour is multiplied by the operating time to find how much power is consumed for the time operated. The total system power is calculated by adding the power consumption rate of both loop and multiplying it by the operating time.
Fig.45, Fig.46, and Fig.47 shows the calculations to find the power consumption of just the TMW060 operating for 800 hours, TMW120 operating for 1100 hours, and both heat pumps for 500 hours respectively.

Model	Voltage Code	Voltage	Voltage Min/Max	Compressor			Total Unit FLA	Min Circuit Amps	SCCR rms Symetrical	SCCR Volts Maximum	Max Fuse/ HACR
				Qty	RLA	LRA					
TMW036	G	208-230/60/1	187/254	1	16.7	79	16.7	20.8	5	600	35
	E	265/60/1	239/292	1	13.5	72	13.5	16.8	5	600	30
	H	208-230/60/3	187/254	1	10.4	73	10.4	13.1	5	600	20
	F	460/60/3	414/506	1	5.8	38	5.8	7.2	5	600	15
	N	575/60/3	518/633	1	3.8	36.5	3.8	4.7	5	600	15
TMW060	G	208-230/60/1	187/254	1	26.3	134	26.3	32.9	5	600	50
	H	208-230/60/3	187/254	1	15.6	110	15.6	19.5	5	600	35
	F	460/60/3	414/506	1	7.8	52	7.8	9.8	5	600	15
	N	575/30/3	518/633	1	5.8	38.9	5.8	7.3	5	600	15
TMW120	G	208-230/60/1	187/254	2	26.3	134	52.6	59.2	5	600	80
	H	208-230/60/3	187/254	2	15.6	110	31.2	35.1	5	600	50
	F	460/60/3	414/506	2	7.8	52	15.6	17.6	5	600	25
	N	575/30/3	518/633	2	5.8	38.9	11.6	13.1	5	600	15
TMW170	H	208-230/60/3	187/254	1	53.6	245	53.6	67.0	5	600	110
	F	460/60/3	414/506	1	20.7	125	20.7	25.9	5	600	45
	N	575/60/3	518/633	1	16.4	100	16.4	20.5	5	600	35
TMW340	H	208-230/60/3	187/254	2	53.6	245	107.2	120.6	5	600	150
	F	460/60/3	414/506	2	20.7	125	41.4	46.6	5	600	60
	N	575/60/3	518/633	2	16.4	100	32.8	36.9	5	600	50

Fig.42 - Heat Pumps Electrical Data

Model	Volts	Hz	Ph	Amps	RPM	HP
0014-F1	115	60	1	1.45	3250	1/8
0014-SF1	115	60	1	1.45	3250	1/8
Motor Type	Permanent Split Capacitor Impedance Protected					
Motor Options	220/50/1, 220/60/1, 230/60/1, 100/110/50/60/1					

Fig.43 - TACO-0014 Power Data

Model	Volts	Hz	Ph	Amps	RPM	HP
All Models	115	60	1	2.0	3250	1/6
Motor Type	Permanent Split Capacitor Impedance Protected					
Motor Options	220/50/1, 220/60/1, 230/60/1, 100/110/50/60/1					

Fig.44 - TACO-0013 Power Data

1 Heat Pump Power in W/h

2 $V_{hp} = 208$

−10 208

3 $A_{hp} = 32.9$

−10 32.9

4 $P_{hp} = V_{hp} \cdot A_{hp}$

$P_{hp} = 6843.2$

5 Pump Power in W/h

6 $V_p = 115$

−10 115

7 $A_p = 1.45$

−10 10

8 $P_p = 2 \cdot \left(V_p \cdot A_p\right)$

$P_p = 333.5$

9 System Power After 800 Hours of Operation in kW

10 $P = 800 \cdot \left(P_{hp} + P_p\right) \cdot \frac{1}{1000}$

$P = 5741.36$

11 Percentage of Power Used by Pump

12 $\frac{P_p}{P_{hp} + P_p} \cdot 100$

$= 4.64698259646$

Fig.45 - TMW060 Only System Power Consumption

1 Heat Pump Power in W/h

2 $V_{hp} = 208$

−10 208

3 $A_{hp} = 59.2$

−10 59.2

4 $P_{hp} = V_{hp} \cdot A_{hp}$

$P_{hp} = 12313.6$

5 Pump Power in W/h

6 $V_p = 115$

−10 115

7 $A_p = 2.0$

−10 10

8 $P_p = 2 \cdot \left(V_p \cdot A_p\right)$

$P_p = 460$

9 System Power Usage for 1100 Hours of Operation in kW

10 $P = 1100 \cdot \left(P_{hp} + P_p\right) \cdot \frac{1}{1000}$

$P = 14050.96$

11 Percentage of Power Used by Pump

12 $\frac{P_p}{P_{hp} + P_p} \cdot 100$

$= 3.60117742845$

Fig.46 - TMW120 Only System Power Consumption

1 Power Consumed From Heat Pumps in W/h

2 $P_{hp1} = 6843.2$

−10 6843.2

3 $P_{hp2} = 12313.6$

−10 12313.6

4 $P_{hp} = P_{hp1} + P_{hp2}$

$P_{hp} = 19156.8$

5 Power Consumed From Pumps in W/h

6 $P_{p1} = 333.5$

−10 333.5

7 $P_{p2} = 460$

−10 460

8 $P_p = 2 \cdot \left(P_{p1} + P_{p2}\right)$

$P_p = 1587$

9 Power Consumed From System after 500 Hours of Operation in kW

10 $P = 500 \cdot P_{hp} + P_p \cdot \frac{1}{1000}$

$P = 9578401.587$

11 Percent of Power Consumed From pump

12 $\frac{P_p}{P_{hp} + P_p} \cdot 100$

$= 7.65047869725$

Fig.47 - System Power Consumption