TFD HW2B - William Van Dyke

Question #1

i.)

In Question #1 the headloss of the heat pump needs to be found when the system is using 15% propylene-glycol antifreeze at a temperature of 30 degrees fahrenheit and a flow rate of 18 GPM. The data provided in Fig.2 was found using 15% methanol antifreeze. Therefore, to calculate the needed values the correction values for 15% methanol antifreeze and 15% propylene-glycol must be found. These values are found in Fig.1.

Next the headloss of the heatpump at the design conditions can be found in Fig.2. This value is then corrected by using the correction factors found in Fig.1. These calculations are shown in Fig.3.

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EWT	Antifreeze Type	Antifreeze %	Cooling			Heating		WPD
			Total Cap	Sensible Cap	Watts	Total Cap	Watts	
30	Water	0%	1	1	1	1	1	1
	Ethanol	5%	0.991	0.991	1.006	0.981	0.994	1.14
		10%	0.981	0.981	1.012	0.961	0.988	1.242
		15%	0.973	0.973	1.018	0.944	0.983	1.295
		20%	0.964	0.964	1.024	0.927	0.977	1.343
		25%	0.959	0.959	1.028	0.917	0.974	1.363
		30%	0.954	0.954	1.031	0.907	0.97	1.383
		35%	0.949	0.949	1.035	0.897	0.967	1.468
		40%	0.944	0.944	1.038	0.887	0.964	1.523
		45%	0.94	0.94	1.041	0.88	0.962	1.58
		50%	0.936	0.936	1.043	0.872	0.959	1.639
	Ethylene Glycol	5%	0.997	0.997	1.002	0.993	0.998	1.04
		10%	0.993	0.993	1.004	0.986	0.996	1.075
		15%	0.99	0.99	1.006	0.98	0.994	1.122
		20%	0.987	0.987	1.008	0.973	0.992	1.163
		25%	0.983	0.983	1.011	0.966	0.99	1.195
		30%	0.979	0.979	1.013	0.958	0.987	1.225
		35%	0.976	0.976	1.016	0.951	0.985	1.279
		40%	0.972	0.972	1.018	0.943	0.982	1.324
		45%	0.969	0.969	1.021	0.937	0.98	1.371
		50%	0.966	0.966	1.023	0.93	0.978	1.419
	Methanol	5%	0.995	0.995	1.004	0.989	0.997	1.069
		10%	0.989	0.989	1.007	0.978	0.993	1.127
		15%	0.984	0.984	1.011	0.968	0.99	1.164
		20%	0.979	0.979	1.014	0.957	0.986	1.197
		25%	0.975	0.975	1.017	0.949	0.984	1.216
		30%	0.971	0.971	1.019	0.941	0.981	1.235
		35%	0.967	0.967	1.022	0.933	0.979	1.286
		40%	0.963	0.963	1.025	0.924	0.976	1.323
		45%	0.959	0.959	1.028	0.917	0.974	1.36
		50%	0.955	0.955	1.03	0.91	0.971	1.399
	Propylene Glycol	5%	0.995	0.995	1.004	0.989	0.997	1.071
		10%	0.989	0.989	1.007	0.978	0.993	1.13
		15%	0.985	0.985	1.01	0.968	0.99	1.206
		20%	0.98	0.98	1.013	0.958	0.987	1.27
		25%	0.974	0.974	1.017	0.947	0.983	1.359
		30%	0.968	0.968	1.021	0.935	0.979	1.433
		35%	0.963	0.963	1.025	0.924	0.976	1.522
		40%	0.957	0.957	1.029	0.913	0.972	1.614
		45%	0.949	0.949	1.034	0.898	0.967	1.712
		50%	0.941	0.941	1.039	0.882	0.962	1.816

Fig.1 - Heat Exchanger Antifreeze Correction Values

SOURCE				LOAD																					
EWT °F	Flow			EWT °F	Flow 18.0 GPM							Flow 27.0 GPM							Flow 35.0 GPM						
	GPM	WPD			HC	Power	HE	LWT	COP	WPD		HC	Power	HE	LWT	COP	WPD		HC	Power	HE	LWT	COP	WPD	
		PSI	FT		Mbtuh	KW	Mbtuh	°F		PSI	FT	Mbtuh	KW	Mbtuh	°F		PSI	FT	Mbtuh	KW	Mbtuh	°F		PSI	FT
20	18.0	0.92	2.13	60	103.4	6.84	80.1	72.0	4.4	0.30	0.69	106.5	6.84	83.2	68.0	4.6	1.59	3.67	109.8	6.84	86.5	66.3	4.7	3.13	7.23
				80	95.1	8.48	66.2	91.0	3.3	0.15	0.35	97.7	8.48	68.7	87.4	3.4	1.42	3.28	100.4	8.48	71.4	85.7	3.5	2.87	6.63
	27.0	3.00	6.93	60	107.8	6.87	84.4	72.0	4.6	0.30	0.69	113.2	7.44	87.8	68.5	4.5	1.59	3.67	114.9	6.86	91.5	66.6	4.9	3.13	7.23
				80	98.8	8.51	69.8	91.0	3.4	0.15	0.35	101.7	8.51	72.7	87.7	3.5	1.42	3.28	104.7	8.50	75.7	86.0	3.6	2.87	6.63
	35.0	5.28	12.20	60	110.0	6.88	86.5	73.0	4.7	0.30	0.69	115.6	7.44	90.2	68.7	4.6	1.59	3.67	117.5	6.87	94.1	66.7	5.0	3.13	7.23
				80	100.7	8.52	71.6	92.0	3.5	0.15	0.35	103.7	8.52	74.7	87.8	3.6	1.42	3.28	106.9	8.52	77.9	86.1	3.7	2.87	6.63
				100	92.3	9.73	59.1	110.5	2.8	0.09	0.21	92.6	9.73	59.4	107.0	2.8	1.28	2.96	95.1	9.73	61.9	105.4	2.9	2.65	6.12
30	18.0	0.84	1.94	60	116.5	6.92	92.9	73.0	4.9	0.30	0.69	120.1	6.91	96.5	69.1	5.1	1.59	3.67	125.7	7.42	100.4	67.2	5.0	3.13	7.23
				80	108.5	8.58	79.3	92.0	3.7	0.15	0.35	111.6	8.58	82.4	88.4	3.8	1.42	3.28	114.9	8.57	85.6	86.6	3.9	2.87	6.63
				100	99.2	9.81	65.7	111.3	3.0	0.09	0.21	101.8	9.81	68.3	107.7	3.0	1.28	2.96	104.5	9.80	71.0	106.0	3.1	2.65	6.12
	27.0	2.72	6.28	60	121.1	6.95	97.4	74.0	5.1	0.30	0.69	126.9	7.45	101.5	69.6	5.0	1.59	3.67	131.1	7.43	105.8	67.5	5.2	3.13	7.23
				80	112.7	8.61	83.3	93.0	3.8	0.15	0.35	116.1	8.61	86.8	88.8	4.0	1.42	3.28	119.8	8.61	90.4	86.8	4.1	2.87	6.63
				100	102.7	9.85	69.1	111.7	3.1	0.09	0.21	105.6	9.84	72.0	108.0	3.1	1.28	2.96	108.6	9.84	75.0	106.2	3.2	2.65	6.12
				120	Operation not recommended														103.5	12.42	61.1	125.9	2.4	2.50	5.78
	35.0	4.84	11.18	60	123.5	6.96	99.7	74.0	5.2	0.30	0.69	129.4	7.45	104.0	69.8	5.1	1.59	3.67	133.8	7.43	108.5	67.6	5.3	3.13	7.23
				80	114.8	8.63	85.4	93.0	3.9	0.15	0.35	118.4	8.63	89.0	88.9	4.0	1.42	3.28	122.3	8.63	92.8	87.0	4.2	2.87	6.63
				100	107.1	9.86	73.5	112.2	3.2	0.09	0.21	107.5	9.86	73.8	108.1	3.2	1.28	2.96	110.7	9.86	77.0	106.3	3.3	2.65	6.12
				120								102.6	12.43	60.2	127.7	2.4	1.19	2.75	105.2	12.43	62.8	126.0	2.5	2.50	5.78
40	18.0	0.69	1.59	60	128.6	7.00	104.7	74.7	5.4	0.30	0.69	132.7	6.99	108.8	70.0	5.6	1.59	3.67	138.6	7.43	113.3	67.9	5.5	3.13	7.23
				80	121.2	8.69	91.5	93.8	4.1	0.15	0.35	124.8	8.68	95.1	89.4	4.2	1.42	3.28	128.6	8.67	99.0	87.3	4.3	2.87	6.63
				100	112.1	9.94	78.2	112.8	3.3	0.09	0.21	115.2	9.93	81.3	108.7	3.4	1.28	2.96	118.4	9.93	84.5	106.8	3.5	2.65	6.12
				120								111.3	12.48	68.7	128.4	2.6	1.19	2.75	114.0	12.48	71.4	126.5	2.7	2.50	5.78
	27.0	2.44	5.64	60	133.4	7.03	109.4	75.2	5.6	0.30	0.69	139.5	7.46	114.0	70.5	5.5	1.59	3.67	144.2	7.43	118.9	68.2	5.7	3.13	7.23
				80	125.6	8.73	95.9	94.4	4.2	0.15	0.35	129.6	8.72	99.9	89.8	4.4	1.42	3.28	133.8	8.72	104.1	87.6	4.5	2.87	6.63
				100	116.1	9.98	82.0	113.3	3.4	0.09	0.21	119.5	9.97	85.4	109.0	3.5	1.28	2.96	123.1	9.97	89.1	107.0	3.6	2.65	6.12
				120	112.0	12.51	69.3	132.8	2.6	0.07	0.16	114.9	12.51	72.2	128.7	2.7	1.19	2.75	117.9	12.51	75.3	126.7	2.8	2.50	5.78
	35.0	4.40	10.16	60	135.8	7.05	111.7	75.5	5.6	0.30	0.69	142.0	7.46	116.5	70.7	5.6	1.59	3.67	147.0	7.44	121.6	68.4	5.8	3.13	7.23
				80	127.9	8.75	98.0	94.6	4.3	0.15	0.35	132.0	8.74	102.2	90.0	4.4	1.42	3.28	136.5	8.74	106.6	87.8	4.6	2.87	6.63
				100	121.2	10.00	87.1	113.9	3.6	0.09	0.21	121.6	10.00	87.5	109.2	3.6	1.28	2.96	125.4	9.99	91.3	107.2	3.7	2.65	6.12
				120	113.7	12.52	71.0	133.0	2.7	0.07	0.16	116.7	12.52	74.0	128.8	2.7	1.19	2.75	119.9	12.52	77.2	126.9	2.8	2.50	5.78
50	18.0	0.43	0.99	60	139.7	7.08	115.5	76.0	5.8	0.30	0.69	144.3	7.08	120.2	70.9	6.0	1.59	3.67	150.5	7.44	125.1	68.6	5.9	3.13	7.23
				80	132.9	8.80	102.9	95.2	4.4	0.15	0.35	137.0	8.79	107.0	90.3	4.6	1.42	3.28	141.4	8.78	111.4	88.1	4.7	2.87	6.63
				100	124.4	10.07	90.1	114.2	3.6	0.09	0.21	128.0	10.06	93.6	109.7	3.7	1.28	2.96	131.7	10.05	97.4	107.5	3.8	2.65	6.12
				120	120.8	12.58	77.9	133.8	2.8	0.07	0.16	123.9	12.58	81.0	129.4	2.9	1.19	2.75	127.2	12.57	84.3	127.3	3.0	2.50	5.78
	27.0	1.69	3.90	60	144.5	7.12	120.2	76.5	5.9	0.30	0.69	150.8	7.47	125.3	71.4	5.9	1.59	3.67	156.1	7.44	130.7	68.9	6.1	3.13	7.23
				80	137.6	8.85	107.4	95.7	4.6	0.15	0.35	142.1	8.84	111.9	90.7	4.7	1.42	3.28	146.9	8.84	116.7	88.4	4.9	2.87	6.63
				100	128.8	10.12	94.2	114.7	3.7	0.09	0.21	132.7	10.11	98.2	110.0	3.8	1.28	2.96	136.8	10.11	102.3	107.8	4.0	2.65	6.12
				120	124.5	12.62	81.5	134.2	2.9	0.07	0.16	127.9	12.61	84.9	129.7	3.0	1.19	2.75	131.5	12.61	88.5	127.5	3.1	2.50	5.78
	35.0	3.28	7.58	60	146.9	7.15	122.5	76.8	6.0	0.30	0.69	153.3	7.48	127.8	71.6	6.0	1.59	3.67	158.8	7.44	133.4	69.1	6.3	3.13	7.23
				80	139.9	8.87	109.6	96.0	4.6	0.15	0.35	144.6	8.87	114.3	90.9	4.8	1.42	3.28	149.6	8.86	119.3	88.5	4.9	2.87	6.63
				100	134.5	10.14	99.9	115.4	3.9	0.09	0.21	135.0	10.14	100.4	110.2	3.9	1.28	2.96	139.4	10.13	104.8	108.0	4.0	2.65	6.12
				120	126.3	12.63	83.2	134.4	2.9	0.07	0.16	129.9	12.63	86.8	129.8	3.0	1.19	2.75	133.7	12.63	90.6	127.6	3.1	2.50	5.78

Fig.2 - Heat Exchanger Headloss for Methanol Antifreeze

1 Head Loss of 15% Methanol Antifreeze @ 30F and 18GPM:

2 1.94

3 Correction Factor for 15% Methanol Antifreeze:

4 1.164

5 Correction Factor for 15% Propylene Glycol Antifreeze:

6 1.206

7 Head Loss for 15% Propylene Glycol Antifreeze @ 30F and 18GPM:

8 $$H_L = \frac{1.94 \cdot 1.206}{1.164}$$

$$H_L = 2.01$$

Fig.3 - Calculations to find Headloss for 15% Propylene-Glycol

ii.)

Question #1 also asked to find the K value corresponding to the piping diameter for the design flow rate. To find the K value it is important to have the heat pump headloss, fluid velocity, and acceleration due to gravity. To find velocity, the flow rate is divided by the cross-sectional area of the pipe. The problem statement specifies 2 inch SRD-11 piping, the dimensions for this are found in Fig.4. All of the calculations required to find the K value are shown in Fig.5.

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.4 - SRD-11 Piping Dimensions

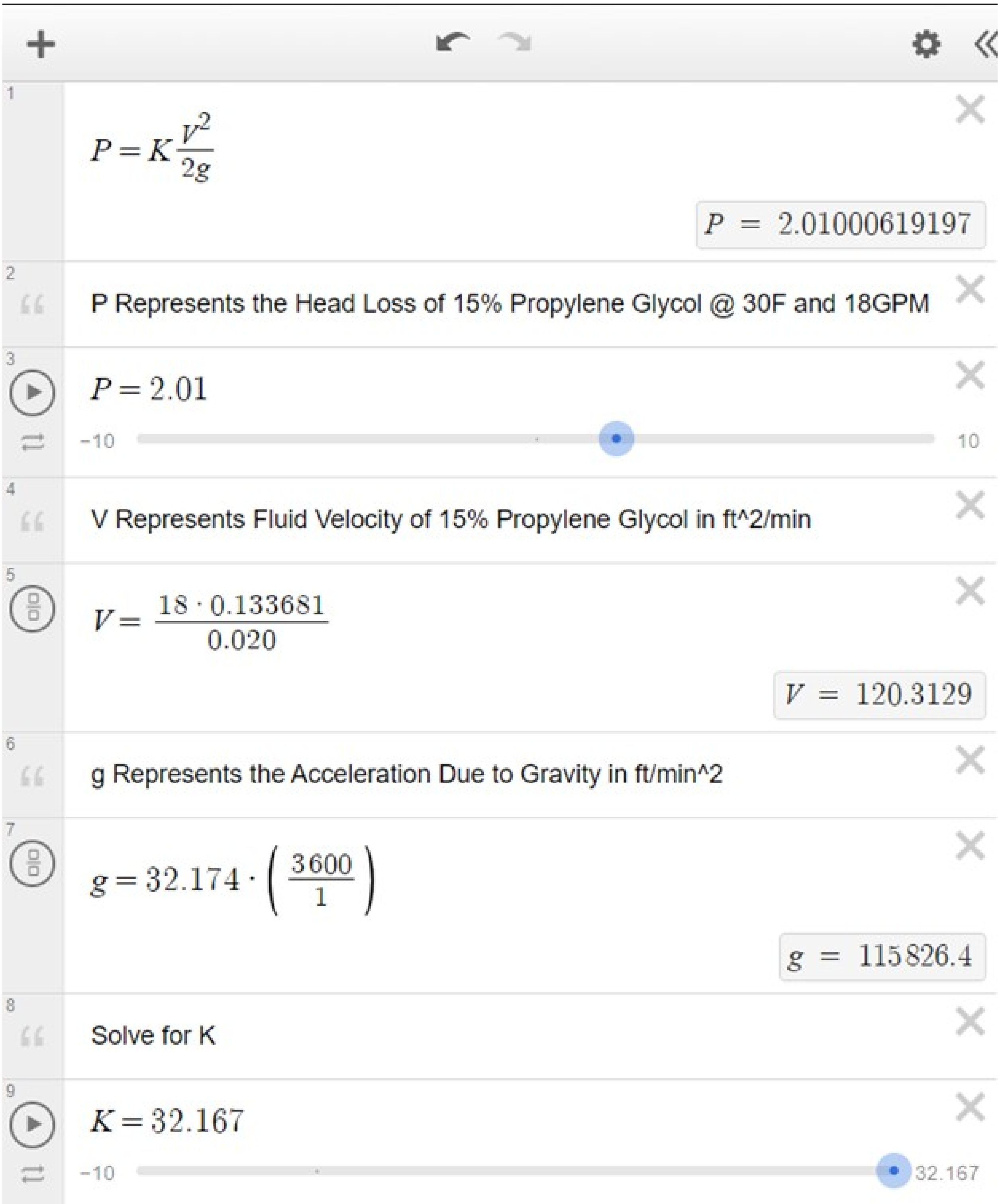
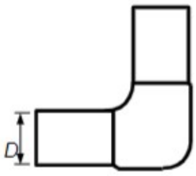


Fig.5 - Calculations to find the K Value Corresponding to The Piping Diameter for the Design Flow Rate

Question #2

In Question #2 the headloss caused by the systems fittings, also known as minor loss, are to be found. The system contains 8x 90 degree elbows. To calculate the minor headloss the K values, velocity and acceleration due to gravity are needed. The K value for 2 inch SRD-11 90 degree elbow fittings are found in Fig.6. The velocity is the same as the velocity calculated in Question #1 part ii. The calculations to find the Minor Loss are presented in Fig.7.



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.6 - K Values Corresponding to SRD-11 Elbows

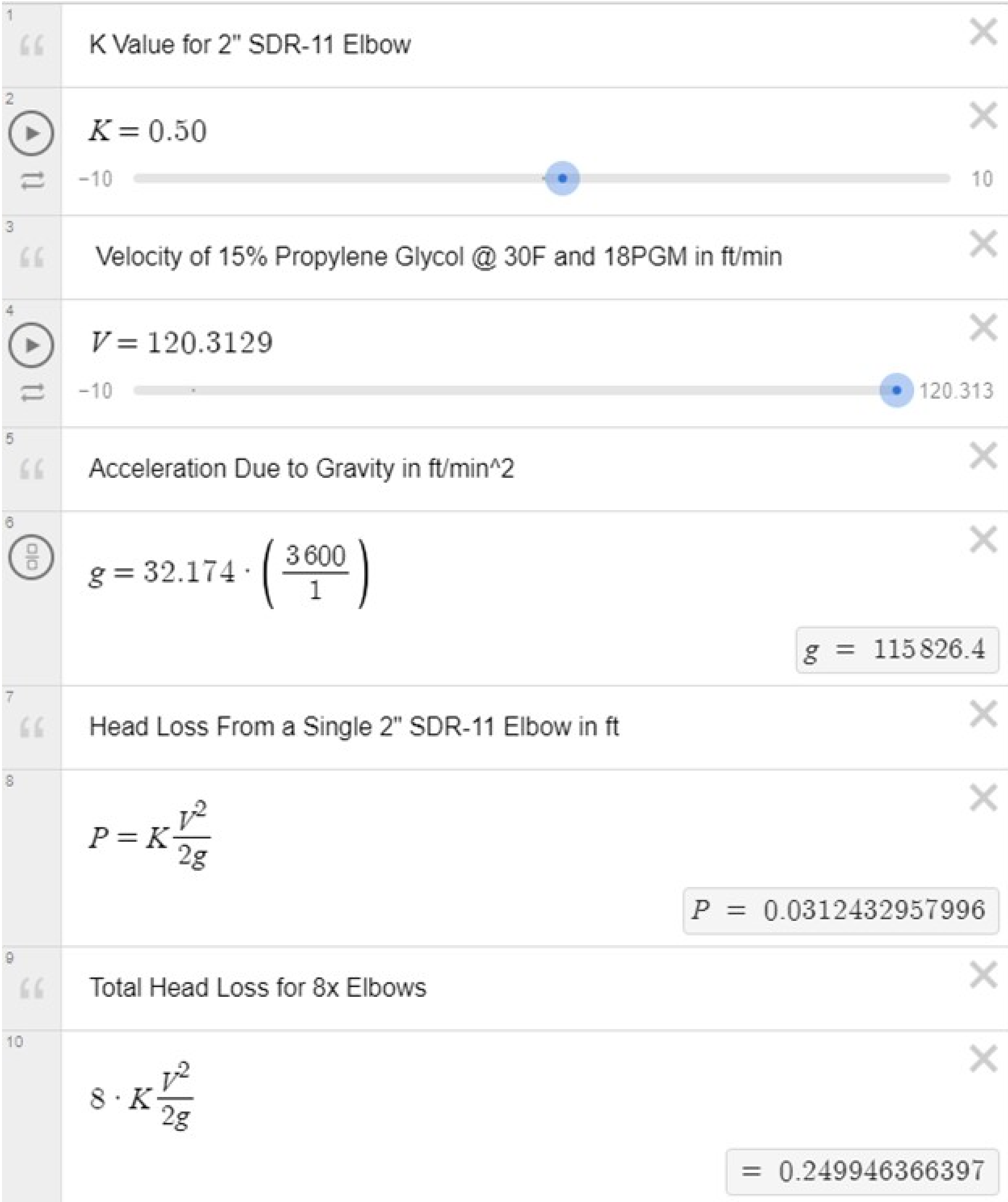


Fig.7 - Calculations to find the Minor Headloss due to Fittings

Question #3

Question #3 asked to calculate the headloss caused from the straight piping, also known as Major Loss. To find Major Loss the friction factor, length of piping, diameter of pipe, velocity of the fluid, and acceleration due to gravity are required. Thus, friction factor must be calculated. The first step of finding friction factor is calculating the Reynolds Number. Reynolds Number is calculated using the velocity of the fluid, diameter of the pipe, and kinematic-viscosity of the fluid. The velocity is found in Question #1 part ii. The Diameter for 2 inch SDR-11 piping is found on Fig.4. The kinematic-viscosity of 15% Propylene Glycol at 30 degrees Farenheit was found using the Engineering Equation Solver (EES) software. The calculations to find Reynolds Number are shown in Fig.8.

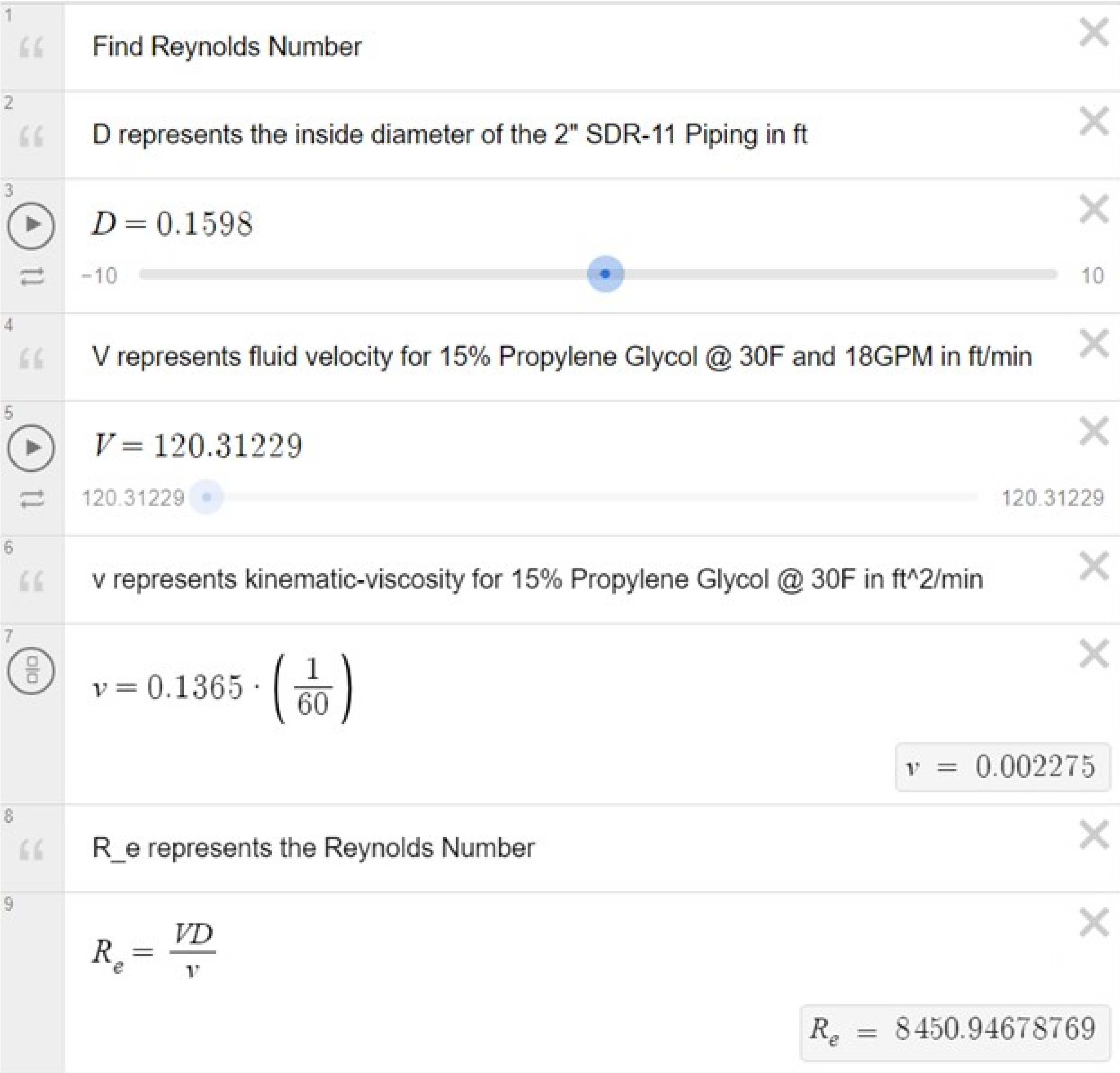


Fig.8 - Calculations to find Reynolds Number

The Reynolds Number for this system indicates that the flow is turbulent. Because the flow is turbulent it is safe to use Swamee and Jaine Equation to find Friction Factor. The last thing needed to find friction factor is the relative roughness for SRD-11 piping, which was found in literature. The calculations to find Friction Factor are shown in Fig.9.

11 Find Friction Factor using the Swamee and Jain method

12 E represents the Relative Roughness in ft

13 $$E = 0.02 \cdot \left(\frac{0.00328084}{1} \right)$$

$$E = 0.0000656168$$

14 f represents the Friction Factor

15 $$f = \frac{0.25}{\left(\log\left(\frac{E}{3.7D} + \frac{5.74}{R_e^{0.9}} \right)^2 \right)}$$

$$f = 0.0331184235178$$

Fig.9 - Calculations to find Friction Factor

Now that Friction Factor has been calculated it is possible to find the Major Loss. Fig.10 displays the calculations used to find the Major Loss.

17 Find the Head Loss in 400' of 2" SDR-11 Piping

18 g represents the acceleration due to gravity in ft/min^2

19 $$g = 32.174 \cdot \left(\frac{3600}{1} \right)$$

$$g = 115826.4$$

20 L represents the length of 2" SDR-11 Piping in the system in ft

21 $$L = 400$$

-10 400

22 $$H_L = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

$$H_L = 5.1800661328$$

Fig.10 - Calculations to find Major Loss

Question #4

Question #4 required the Headloss from the heat exchangers to be found. The problem statement provided the relationship between headloss and flowrate. However, this relationship was not based on a 15% Propylene Glycol brine flowing through it, therefore, it is nescesary to apply a correction which was provided in the problem statement. The calculations for the heat exchanger headloss are presnted in Fig.11.

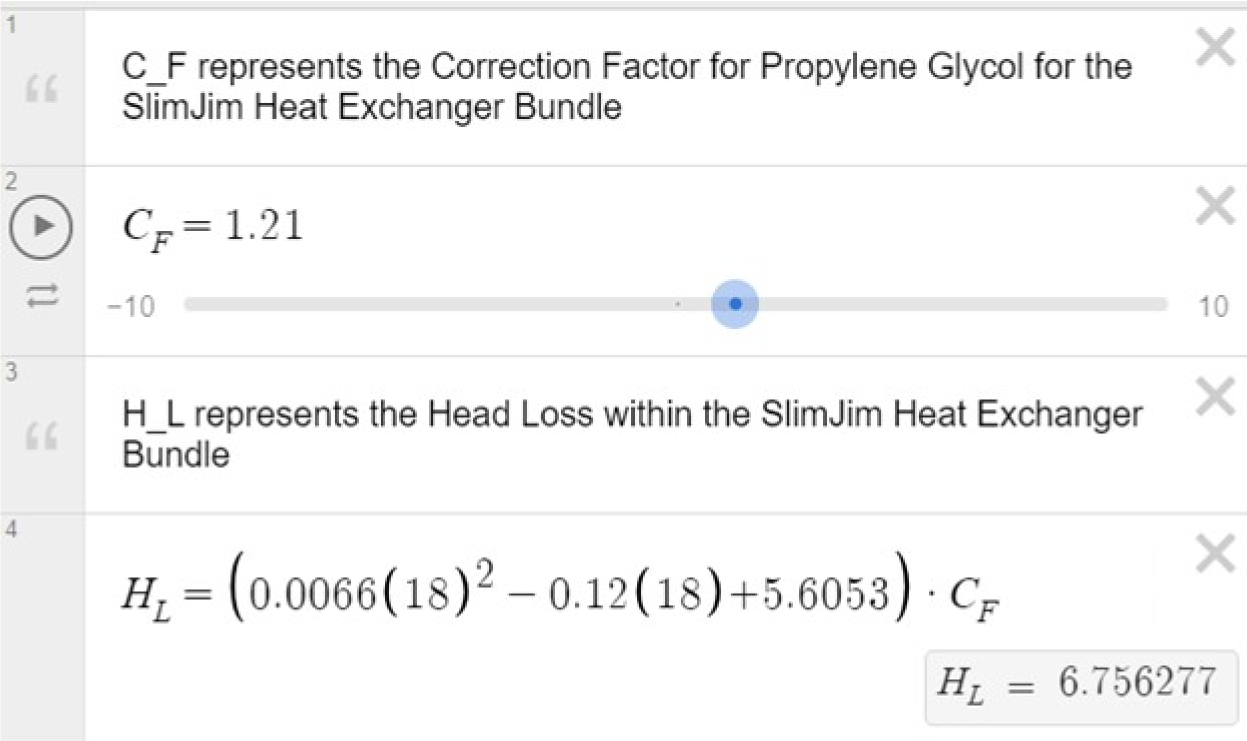


Fig.11 - Calculations to find the Heat Exchanger Headloss

Question #6

Question #6 requested a summary of all the losses in this systems loop. A summary for the Total Headloss is shown in Fig.12.

Major Losses		
Size/Type	Lenth (ft)	Head Loss (ft)
2" SDR-11 Piping	400	5.18
Minor Losses		
Fitting	Quantity	Head Loss (ft)
2" SDR-11 Elbow	8	0.2499
Equipment Losses		
Equipment		Head Loss (ft)
Heat Pump		2.01
Heat Exchanger		6.7562
Total Head Loss (ft)		
14.1961		

Fig.12 - Summary of Total Headloss

Question #5

Question #5 asked for a tool developed by the student that will calculate the losses caused by the heat exchanger as a function of flow rate. The tool was developed in Python and is shown below.

```
def calc_heat_exchanger_head_loss(flow_rate:int,correction_factor:int=1):
    head_loss = (0.0066*(flow_rate**2)-0.12*flow_rate+5.6053) * correction_factor
    return head_loss

calc_heat_exchanger_head_loss(18,1.21)
```

Question #7 and Question #8

Questions #7 and #8 were closely related. In Question #7 the student was asked to select a pump based on the flowrate and required headloss. Fig.13 shows the design requirements, then selecting the closest minimally oversized pump the outcome is the Taco Circulator 0011.

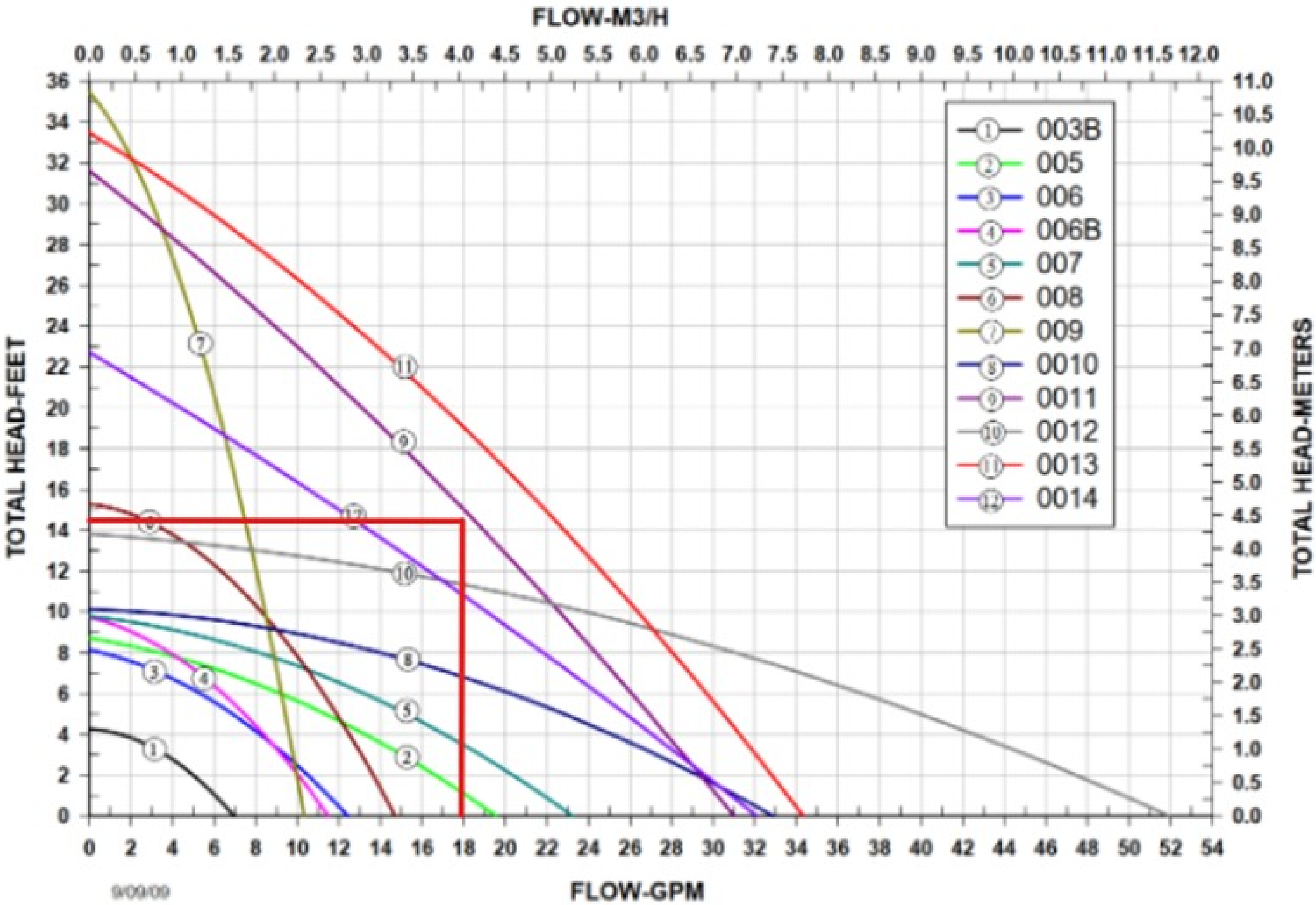


Fig.13 - Taco Circulator Pump Selction

The rest of Question #7 and Question #8 ask the student to develp a tool that plots the pump curve using data points collected from the Fig.13 and plots the system curve. The tool should also plot the system's Actual Opperating Point (AOP). This tool is shown below and was developed with Python.

```
pump_head_loss =
[31.5,30.8,30,29,28.5,27.5,26.8,25.8,25,24,23,22,21,20.1,19,18.1,17,16.1,15,14,12.
9,11.9,10.8,9.5,8.4,7.2,6,5,3.8,2,0.8,0]

def
plot_system_and_pump_curve(pump_head_loss:list[int],total_head_loss:int,flow_rate:
int):

    # FIND EQUATION FOR PUMP CURVE
    flow_rates = np.linspace(0,len(pump_head_loss)-1,len(pump_head_loss))
    pump_curve = np.poly1d(np.polyfit(x=flow_rates,y=pump_head_loss,deg=3))

    # CALCULATE THE K VALUE FO RTHE SYSTEM CURVE
    k = total_head_loss/(flow_rate**2)

    # CALCULATE HEADLOSS FOR AND EQUATION FOR SYSTEM CURVE
    system_head_loss = []
    for i in range(len(pump_head_loss)):
        aop = k*(flow_rates[i]**2)
        system_head_loss.append(aop)

    # PLOT PUMP CURVE
    plt.plot(flow_rates,pump_curve(flow_rates))
    # PLOT SYSTEM CURVE
    plt.plot(flow_rates,system_head_loss)
    # PLOT AOP FOR 18-GPM
    plt.scatter(x=flow_rate,y=total_head_loss,color="orange")

    # MAKE THE PLOT LOOK NICE
    plt.title("Pump and System Curve")
    plt.legend(['Pump','System'])
    plt.xlabel("Flow Rate - GPM")
    plt.ylabel("Head Loss - feet")
    plt.margins(x=0,y=0)
    plt.grid(which="major")
    plt.yticks(ticks=
[0,2,4,6,8,10,12,14,16,18,20,22,24,26,28,30,32,34,36,38,40,42])
    plt.xticks(ticks=[0,2,4,6,8,10,12,14,16,18,20,22,24,26,28,30,32])

    # SAVE FIGURE
    plt.savefig("pump_curve.png")

plot_system_and_pump_curve(pump_head_loss=pump_head_loss,total_head_loss=14.1961,f
low_rate=18)
```

In the above code the list titled "pump_head_loss" represents the headloss of the Taco Circulator 0011 that was collected based on Fig.13. The result of running the above tool is show in Fig.14.

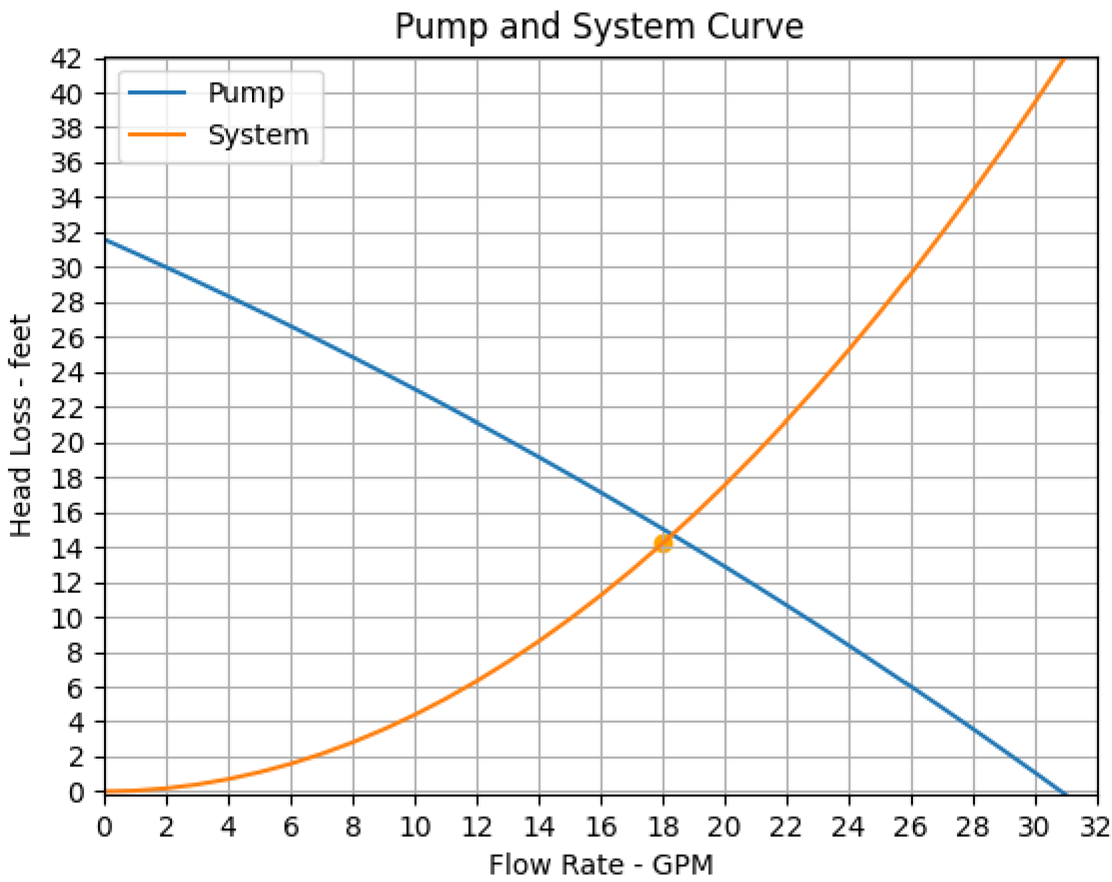


Fig.14 - Pump and System Curve

The orange dot represents the systems AOP.