Design of Real Piping Systems

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Contents

(7 Relevant Pages) 10 total with appendix, cover and contents

Piping Material and Dimension Considerations

Piping Material

Considered as the piping material were PVC, Stainless Steel and the chosen Copper. Copper was settled on for its excellent thermal properties and corrosion resistance. Stainless steel stood out as a similarly functional option but is more expensive when compared to copper piping while having no extra advantage over copper. PVC, while much cheaper and versatile, is considerably less durable and widely uncommon as an industrial piping solution. Copper is however a widely used piping material and so seemed an excellent choice for the application.

Piping Dimensions

The pipe's internal diameter for the full loop is to be kept at a constant diameter of 25 Millimetres. Considered were the most common commercially available copper piping sizes. 25mm, 20mm and 15mm.

The various sizes were considered through analysis of the impact on Fluid Velocity and Head Loss, with Air Entrainment and Noise being the primary focus followed by minimising Head Loss. At the required flow rate and set condenser diameter the flow rate was constantly high enough to ensure a lack of fouling and low enough to avoid corrosion at the entrance and exits. The below table highlights how a 25mm pipe maintains a good balance between all the aforementioned factors.

Table 1: 25mm pipe. Pump driven flow rate in orange. Required Flow Rate in Yellow. Green indicates Ideal conditions. Blue is fast enough to prevent entrainment but faster than the recommendation for avoiding excessive noise.

Flow Rate (m^3/s)	Velocity Loop (m/s)	Velocity Condenser (m/s)	HL per 100m (m)
0.000255	0.52	1.60	10.12
0.00035	0.71	2.20	18.32
0.000416	0.85	2.62	25.53
0.00045	0.92	2.83	29.73
0.0005	1.02	3.14	36.51
0.000554	1.13	3.48	44.63
0.0006	1.22	3.77	52.20
0.00063	1.28	3.96	57.46

At the pump driven flow rate, the velocity is well within recommended limits for Sound and Entrainment for the main loop. The Condenser at 3.96 m/s is above the recommendation for noise by 205% but this noise would be localised to the condenser. Furthermore, this was unavoidable given the cooling requirements do not allow for variation in the condensers pipe diameter.

Table 2: Piping Dimensions and Materials Summary

Properties	Piping System	Condenser	Units
Material	Copper	Copper	
Diameter	0.025	0.01423	m
Roughness	0.000002	0.000002	m
Relative Roughness	0.00008	0.000140548	

System Characteristic

Required flow rate of 2.55E-4 m^3/s

Table 3: Reynolds Number Calculations and Liquid Properties by region. Condenser density is calculated as an average of the other two.

Properties	Before Condenser	Condenser	After Condenser	Units
T (Temperature)	10°	10° to 30°	30°	Celsius
ρ (Density)	999.7	997.675	995.65	Kg/m^3
μ (Dynamic Viscosity)	0.001306	0.0010516	0.0007972	Pa * s
v (Velocity)	0.519481734	1.603394904	0.519481734	m/s
d (Diameter)	0.025	0.01423	0.025	m
Reynolds Number	**9941.154091**	**21646.31187**	**16219.957**	

Table 4: Friction Factors by Region. Calculated with the Haaland Equation.

Value	Before Condenser	Condenser	After Condenser
Friction Factor (Haaland)	**0.031017428**	**0.025486248**	**0.027265837**

Equation Workings

Below is the process used computationally written out by hand, the characteristic equation is shown at the end as $\boldsymbol{H_{total} = Q^2 (35043750.85) + 1.71}$ where the head loss from the strainer and the height difference between the reservoir and highest point are taken into account in the 1.71m constant. The height difference is 1.5m with a calculated head loss of 0.21m (Spirax Sarco, 2006b) for the chosen strainer.

The chosen strainer is a *Spirax Sarco - Y Type Brass 3/4'' Screwed Strainer* (Spirax Sarco, 2006a).

Equation 1: Depicted is the derivation of the relevant system characteristic

$$H_{loss} = (K_{loss} + f\frac{L}{D})\frac{v^2}{2g} \quad (1)$$

$$H_{total} = (K_{lossBC} + f_{BC}\frac{L}{D})\frac{v^2}{2g} + (K_{lossC} + f_C\frac{L}{D})\frac{v^2}{2g} + (K_{lossAC} + f_{AC}\frac{L}{D})\frac{v^2}{2g} + Strainer + Height \quad (2)$$

$$H_{total} = (K_{loss} + f\frac{L}{D})\frac{(\frac{4Q}{\pi D^2})^2}{2g} + (K_{loss} + f\frac{L}{D})\frac{(\frac{4Q}{\pi D^2})^2}{2g} + (K_{loss} + f\frac{L}{D})\frac{(\frac{4Q}{\pi D^2})^2}{2g} \quad (3)$$

$$H_{total} = (3.48 + f\frac{7.5}{0.025})\frac{8Q^2}{\pi^2 D^4 g} + (1.66 + f\frac{7}{0.01423})\frac{8Q^2}{\pi^2 D^4 g} + (11.8 + f\frac{11}{0.025})\frac{8Q^2}{\pi^2 D^4 g} \quad (4)$$

$$H_{total} = Q^2((12.78)\frac{8}{\pi^2 D^4 g} + (13.96)\frac{8}{\pi^2 D^4 g} + (19.9)\frac{8}{\pi^2 D^4 g}) \quad (5)$$

$$H_{total} = Q^2(2703286.362 + 28131121.87 + 4209342.613) \quad (6)$$

$$H_{total} = Q^2(35043750.85) + 1.71 \quad (7)$$

Kloss Values

Kloss values for each section are show below *(Çengel, Cimbala and Turner, 2012, p.552,553)*. Data for constrictions and expansions calculated using $K_l = \left(1 - \frac{d^2}{D^2}\right)^2$ and $K_l = 0.42\left(1 - \frac{d^2}{D^2}\right)$. Where *d* and *D* are pipe diameters and *d* < *D*.

Table 5: Kloss Before Condenser

Causes	Quantity	K Loss Values	Totals
90° Smooth Threaded Bends	3	0.9	2.7
Entrance from Reservoir	1	0.5	0.5
Entrance to Condenser	1	0.2839	0.2839
Total			**4.4839**

Table 6: Kloss Condenser

Causes	Quantity	K Loss Values	Total
180° Flanged Bends	6	0.2	1.2
Exit to Pipes	1	0.457	0.457
Total			**1.657**

Table 7: Kloss after condenser

Causes	Quantity	K Loss Values	Total
90° Smooth Threaded Bends	2	0.9	1.8
Globe Valve	1	10	10
Total			**11.8**

Plotted System Characteristic

The system characteristic curve is plotted across 10 data points with increments of 5.0E-5 m^3/s converted to flow rate per hour.

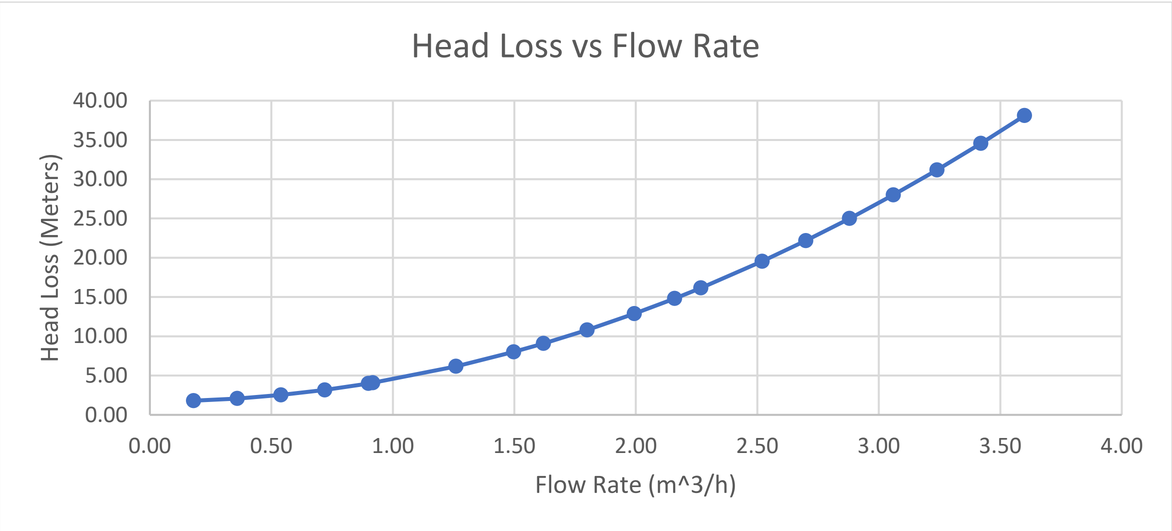

Figure 1: System Characteristic plotted

Pump Considerations

The pump chosen is the GROUNDFOS CM-Basic CM1 (GROUNDFOS, 2018b). This pump provides ample head to drive the flow at a calculated rate of 6.34E-4 m^3/s which is above the 2.55E-4 m^3/s required as per coolant considerations.

Flow rate was calculated as the intercept of the pump characteristic: $H = -3.0771(Q*3600)^2 - 1.8363(Q*3600) + 36.227$ and the system characteristic equation above.

This flow rate still maintains a high enough velocity to prevent entrainment and low enough to prevent excessive noise as shown in *table 1 on page 3.*

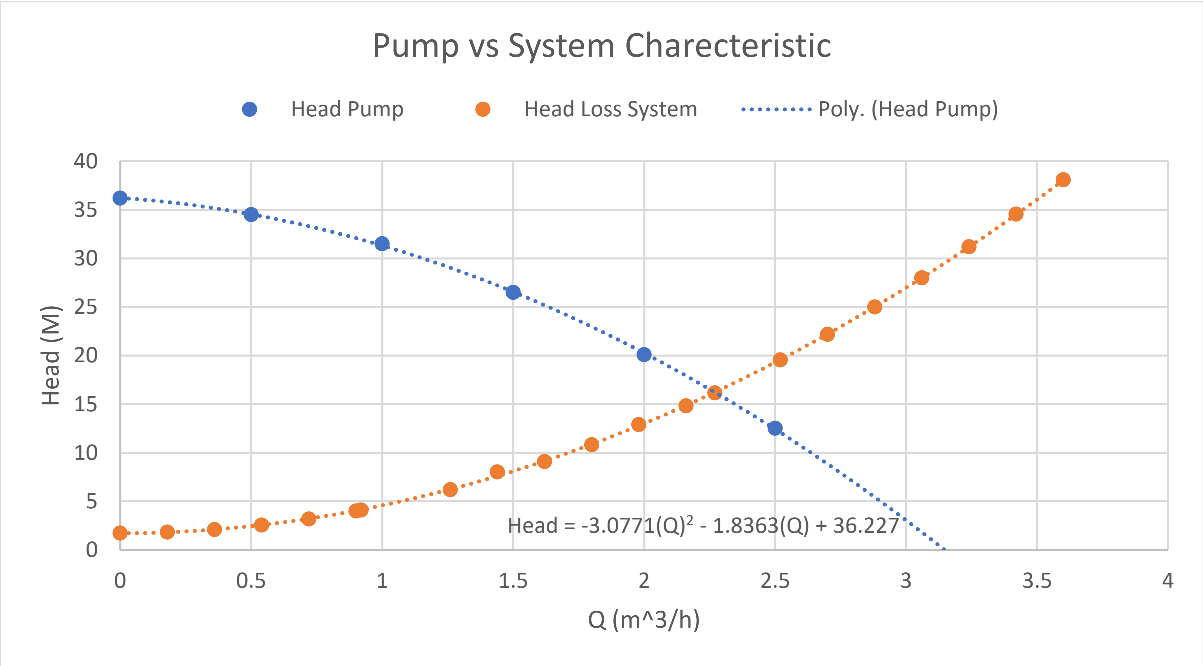

Figure 2: System Characteristic plotted against the Pump Characteristic

The schematic pump location is imperfect. At its current location, it is likely to be damaged, leading to an overall less reliable system. The pump is at the lowest point of the system where particulates and other non-fluid objects are likely to gather. Further the losses going through the condenser are significant in effecting the NPSH and so it is proposed the pump is moved just before the condenser to prevent these problems.

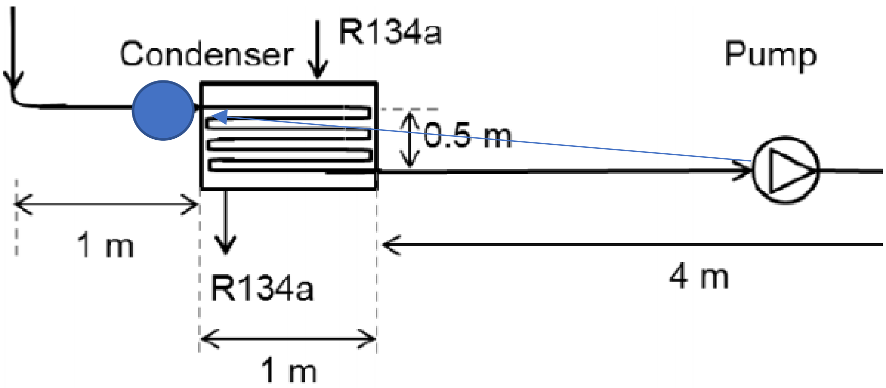

Figure 3: Proposed pump location

Pump Cavitation

Below are the calculations for the net positive suction head at the pump inlet. Provided this value is above the manufactures requirements this will ensure cavitation does not occur in the pump.

$$NPSH = H_{atm} + H_{belowResevoir} - H_f - H_{vp} \quad (1)$$

$$H_{atm} = \frac{101325}{\rho g} = 10.36m \quad (2)$$

$$H_{belowResevoir} = 3m \quad (3)$$

$$H_{vp} = \frac{1.2282 * 10^3}{\rho g} = 0.125m \quad (4)$$

$$H_f = 1.07_{LossBC} + 0.21_{LossStrainer} = 1.28m \quad (5)$$

$$NPSH = 10.36 + 3 - 1.13 - 0.125 = 11.955m \quad (6)$$

Figure 4: Calculating the Net Positive Suction Head

NPSH at the pump is 11.955m the manufacturer recommends 1.8m of NPSH to avoid cavitation and ensure a long pump life *see fig 5 below*. The 11.955m is greater than 1.8m and so meets the requirements.

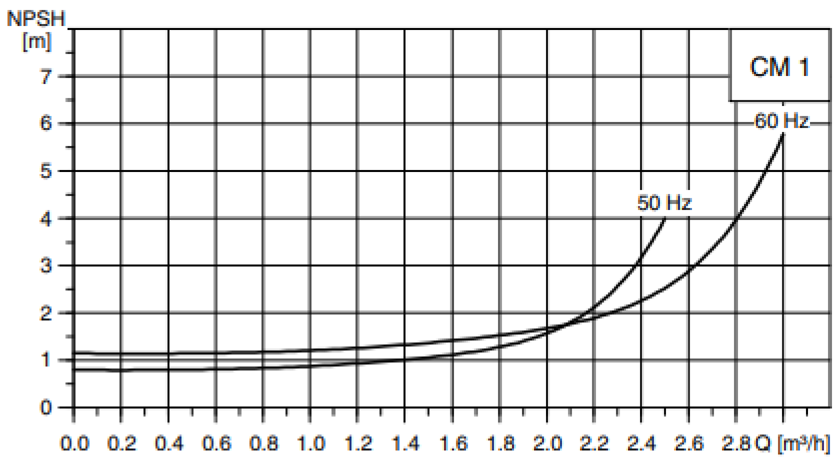

Figure 5: Except from pump technical showing NPSH vs Flow rate *(GROUNDFOS, 2018a)*

Half Flow Rate

Below are the calculations to ascertain the Kloss value of the globe valve so that the system flow rate is half the required flow rate of 2.55E-4 m^3/s, this is taking the pump head to be a constant set at the value 16.234m as that is the operating head normally. Friction factors are also considered to be constant.

$$H_{total} = Q^2((12.78)\frac{8}{\pi^2 D^4 g} + (13.96)\frac{8}{\pi^2 D^4 g} + (K_{globe} + 1.8 + f\frac{11}{0.025})\frac{8Q^2}{\pi^2 D^4 g}) \quad (1)$$

$$H_{total} = Q^2(2703286.362 + 28131121.87 + (K_{globe} + 1.8 + 0.027\frac{11}{0.025})\frac{8Q^2}{\pi^2 D^4 g}) \quad (2)$$

$$H_{total} = Q^2(30854408.23 + (K_{globe} + 1.8 + \frac{0.027 * 11}{0.025})\frac{8}{\pi^2 D^4 g}) \quad (3)$$

$$H_{total} = Q^2(30854408.23 + 211524.75(K_{globe} + 13.68)) \quad (4)$$

$$Q = 0.000255/2 = 0.000127 \quad (5)$$

$$H_{total} = (0.000127)^2(30854408.23 + 211524.75 * (K_{globe} + 13.68)) \quad (6)$$

Pump head = 16.234m under normal conditions. Taking that to be constant.

$$16.234 = (0.000127)^2(30854408.23 + 211524.75(K_{globe} + 13.68)) \quad (7)$$

$$K_{globe} = 4097.6 \quad (8)$$

Characteristic Equation:

$$H = Q^2(900491882.4) + 1.71 \quad (9)$$

Figure 6: Calculation for Kloss given half flow and a constant pump head

The Kloss value of the globe valve comes out to be 4097.6 at a flow rate of 1.27E-4 m^3/s. Below the characteristic equation above is plotted alongside the standard system characteristic and the constant pump head.

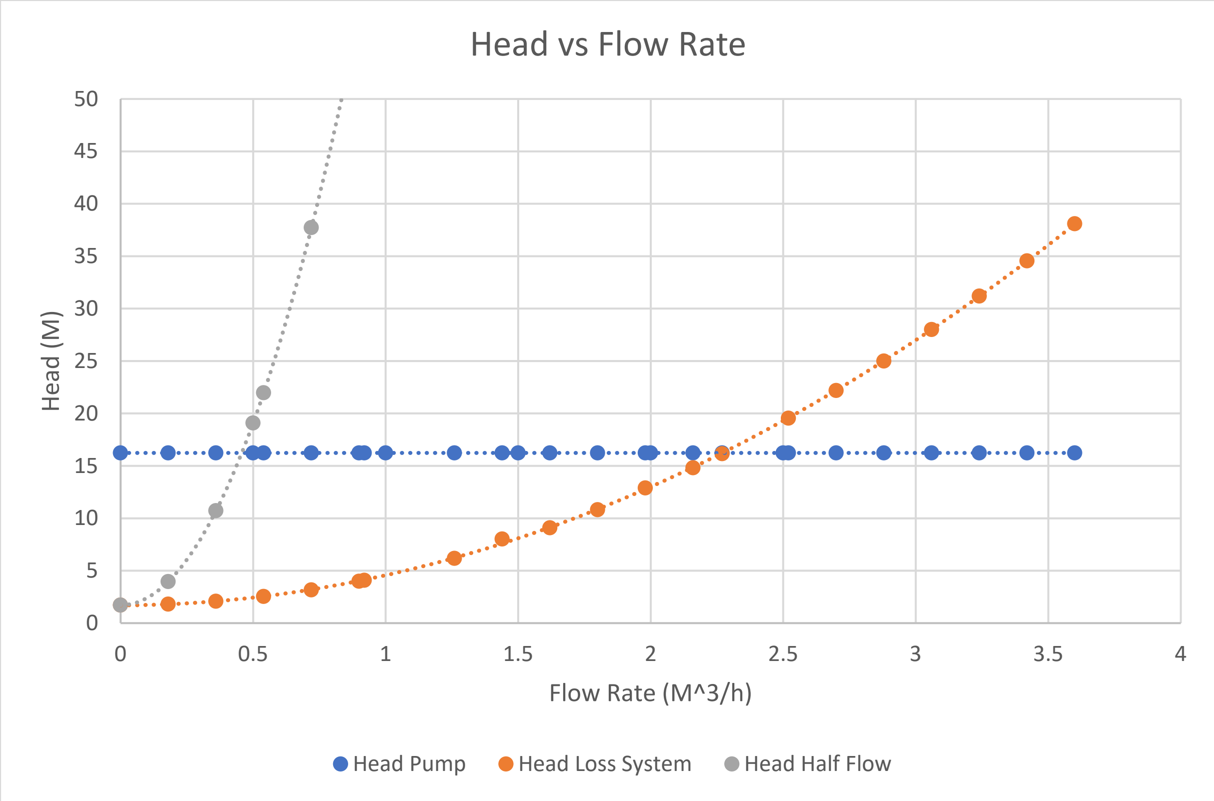

Figure 7: Constant Head Pump. Compared to System Head and Half Flow Head

Comments on Performance

The system should perform quite well over time, with no unforeseeable issues maintaining the required flow rate as even with some deterioration or loss of driving head the systems flow rate is 149% higher than the required rate for the plants function.

The system due to its open reservoir (not a sealed system) has the potential to lose fluid overtime, this would result reservoir water level dropping and effecting both NPSH and adding extra Head for the pump to drive due to the change in height between the water level and systems highest point. So, the systems fluid would have to be replenished over time.

Finally, the pump is well situated downstream of the strainer and above the lowest point in the system hence minimising the potential damage from particulates.

Reference list

Çengel, Y.A., Cimbala, J.M. and Turner, R.H. (2012). *Fundamentals of thermal-fluid sciences*. New York: Mcgraw-Hill Higher Education, p.552,553.

GROUNDFOS (2018a). *CM Installation and operating instructions*. [online] Available at: https://api.grundfos.com/literature/Grundfosliterature-5606159.pdf.

GROUNDFOS (2018b). *GRUNDFOS PUMPS FOR HOME AND GARDEN*.

Spirax Sarco (2006a). *Pipeline strainers for steam, liquids and gases steam specialties*.

Spirax Sarco (2006b). *Pressure Drop Information (Resistance to Flow of Water) for Strainers*.

Subramanian, R. (n.d.). *Pipe Flow Calculations*. [online] *web2.clarkson.edu*. Available at: https://web2.clarkson.edu/projects/subramanian/ch330/notes/Pipe%20Flow%20Calculations.pdf [Accessed 6 Oct. 2020].