Samuel Gonzalez

University of Florida Nuclear Sciences Building

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Gainesville, FL 32611

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Gainesville, FL 32611

June 2, 2023

Dear Mr. Gonzalez,

The pipe loss experiment determines frictional losses in a hydraulic circuit composed of a large pipe, a small pipe, and an elbow by analyzing water temperature, flowrate, and pressure difference. These measured parameters characterize the system's properties, and from them, values can be calculated for head loss, friction factor, Reynold's number, loss coefficients, and roughness factor. Additionally, each measured and calculated parameter has a correlating uncertainty value.

Defining the system's layout and properties is deemed crucial for understanding this experiment. Using a LabVIEW program connected to the pipe setup, students are recording values for water temperature, pressure in the pump, and differential pressure in the large pipe, small pipe, and elbow. After combining this data with known parameters, such as local gravity and fluid density, head loss is calculated to determine the amount of mechanical energy transformed into unwanted internal energy. Subsequently, values are calculated for velocity, Reynold's number, friction factor, loss coefficient, and roughness factor to characterize the frictional effects on the system due to differing pipe sizes. Finally, for this lab, it is assumed that the flow is incompressible, the fluid is inviscid and distilled, elevation differences are negligible, and local gravity, ambient temperature, and ambient pressure are all constant.

The pipe system used in this lab contained one large and one small straight pipe with inner diameters of 18.877 mm and 9.365 mm, respectively; the segment of large piping also hosted a 90° elbow. Powered by a 1.5-hp pump, the hydraulic circuit included three differential pressure transducers, one transducer measuring the pump's output gage pressure, three electronic flowmeters, and various analog devices. To complete the experiment, parameters were measured such as ambient temperature, barometric pressure, and the apparatus' dimensions. Next, the pump was turned on and the maximum flow rate was recorded for both pipes. Subsequently, data was collected for the pipes at ten different flow rates; the large pipe endured three runs with varying values plugged into the LabVIEW program for sampling time, frequency, and run time while the small pipe was run once. To minimize error, multiple measurements were taken. Additionally, safety glasses and closed toed shoes were worn by all students for safety.

In conclusion, the pipe loss laboratory experiment utilized a piping setup that allowed for data acquisition of flowrate, pressure loss, and temperature; furthermore, values were calculated to determine which piping setup would deliver the most effective cooling system. From calculations, it was found that head loss h_L in the large pipe at a nominal flowrate of 33.04 LPM (with the control valve 80% open) had a value of 8.5 ± 0.546 inches, while the result of the 80% open valve (30.4 LPM) in the small pipe was 175.3 ± 0.184 inches, much larger than head loss in the large pipe. The Reynolds number was between 1250 and 110,000, while the friction factor yielded values between 0.013 and 0.18; these calculated parameters were both unitless. At a nominal flowrate of 20.587 LPM, the loss coefficient for the 90° elbow was found to be 1.57. Finally, the experimental roughness factor was calculated as 8.82×10^{-4}, but the standard roughness factor for a copper pipe was identified as 7.94×10^{-5}; the experimental value was approximately eleven times bigger than the industry standard, perhaps due to the age and overuse of the pipes in the laboratory. From the acquired data, it was concluded that the large pipe had an overall lower head loss than the smaller, and the values became more accurate as the sample per iteration increased.

Sincerely,

Conor Bowman   Alex Carr   Allison Porras   David Reyes-Tobar

Data Sheet for Frictional Losses in Piping Systems

Date: 24 May 2023
Time: 11:00am

Team Members:
Conor Bowman
Alex Carr
Allison Porras
David Reyes-Tobar

Ambient Temperature (°C): 22.2
Ambient Pressure (mm Hg): 754.9
Inner diameter large pipe (mm): 18.877
Uncertainty large pipe (mm): ±0.025
Inner diameter small pipe (mm): 9.365
Uncertainty small pipe (mm): ±0.025

Experimental Data

Table 1: Large Pipe – Run 1 – 1 sample/iteration, sampling rate 400 samples per second, run time 5 seconds.

Large pipe Nominal flowrate (LPM)	**Actual flow rate (LPM)**	**Flowrate uncertainty (± LPM)**	**Head loss Δh (inches)**	**Standard deviation of head loss (inches)**	**Total uncertainty of head loss (± inches)**	**Temperature (°C)**	**Uncertainty in temp. (°C) (std dev + instrument error)**
41.3	41.491	1.244	13.375	0.403	0.445	26.73	0.201
37.17	37.618	1.128	10.783	0.399	0.427	27.22	0.204
33.04	33.213	0.996	9.199	0.404	0.424	28.12	0.211
28.91	28.557	0.856	7.220	0.400	0.413	28.43	0.213
24.78	24.821	0.744	5.805	0.400	0.409	28.73	0.215
20.65	20.655	0.619	4.533	0.396	0.401	28.98	0.217
16.52	16.595	0.497	3.501	0.398	0.401	29.24	0.219
12.39	12.244	0.367	2.709	0.400	0.402	29.50	0.221
8.26	8.261	0.247	2.834	0.403	0.405	29.74	0.223
4.13	4.207	0.126	2.192	0.394	0.396	30.03	0.225
0	0.886	0.0265	1.785	0.403	0.404	30.24	0.227

Table 2: Large Pipe – Run 2 – 200 samples/iteration, sampling rate 400 samples per second, run time 5 seconds.

Large pipe Nominal flowrate (LPM)	**Actual flow rate (LPM)**	**Flowrate uncertainty (± LPM)**	**Head loss Δh (inches)**	**Standard deviation of head loss (inches)**	**Total uncertainty of head loss (± inches)**	**Temperature (°C)**	**Uncertainty in temp. (°C) (std dev + instrument error)**
41.3	41.350	0.274	12.814	3.811	3.815	27.42	0.206
37.17	37.699	0.114	10.197	0.263	0.300	27.79	0.209
33.04	33.323	0.121	8.189	0.495	0.508	28.22	0.212
28.91	28.600	0.106	6.377	0.163	0.187	28.52	0.214
24.78	24.848	0.0415	5.153	0.243	0.254	28.83	0.216
20.65	20.644	0.045	3.866	0.282	0.287	29.08	0.218
16.52	16.645	0.052	2.858	0.156	0.161	29.30	0.220
12.39	12.272	0.017	1.970	0.245	0.247	29.53	0.222
8.26	8.265	0.028	2.032	0.394	0.396	29.85	0.224
4.13	4.222	0.015	1.405	0.213	0.214	30.12	0.226
0	0.886	0.023	1.115	0.320	0.320	30.20	0.226

Table 3: Large Pipe – Run 3 – 200 samples/iteration, sampling rate 400 samples per second, run time 10 seconds.

Large pipe Nominal flowrate (LPM)	**Actual flow rate (LPM)**	**Flowrate uncertainty (± LPM)**	**Head loss Δh (inches)**	**Standard deviation of head loss (inches)**	**Total uncertainty of head loss (± inches)**	**Temperature (°C)**	**Uncertainty in temp. (°C) (std dev + instrument error)**
41.3	41.253	1.237	12.694	0.340	0.681	27.60	0.207
37.17	37.787	1.133	10.075	0.232	0.464	27.90	0.209
33.04	33.285	0.998	8.513	0.546	1.093	28.30	0.212
28.91	28.559	0.856	6.499	0.177	0.355	28.57	0.214
24.78	24.830	0.744	5.119	0.240	0.480	28.88	0.216
20.65	20.587	0.617	3.863	0.218	0.436	29.13	0.219
16.52	16.577	0.497	2.797	0.198	0.396	29.35	0.220
12.39	12.254	0.367	2.016	0.167	0.334	29.61	0.222
8.26	8.257	0.247	2.144	0.298	0.596	29.95	0.224
4.13	4.218	0.126	1.490	0.240	0.481	30.17	0.226
0	0.877	0.0263	1.089	0.2424	0.484	30.16	0.226

Table 4: Small Pipe – 200 samples/iteration, sampling rate 400 samples per second, run time 10 seconds.

Large pipe Nominal flowrate (LPM)	Actual flow rate (LPM)	Flowrate uncertainty (± LPM)	Head loss Δh (inches)	Standard deviation of head loss (inches)	Total uncertainty of head loss (± inches)	Temperature (°C)	Uncertainty in temp. (°C) (std dev + instrument error)
38.0	38.069	1.142	264.373	0.228	3.745	30.62	0.230
34.2	34.371	1.031	215.431	0.191	3.052	30.75	0.231
30.4	30.690	0.921	175.308	0.184	2.486	30.83	0.231
26.6	26.435	0.793	136.409	0.178	1.937	30.93	0.232
22.8	22.830	0.685	105.527	0.172	1.502	31.01	0.233
19.0	19.343	0.580	80.407	0.162	1.150	31.18	0.234
15.2	14.966	0.449	51.838	0.173	0.751	31.27	0.235
11.4	11.135	0.334	30.421	0.149	0.455	31.35	0.235
7.6	7.465	0.224	33.487	0.224	0.524	31.51	0.237
3.8	3.903	0.117	9.671	0.211	0.251	31.53	0.237
0	0.441	0.0132	0.419	0.210	0.210	31.52	0.237

Uncertainty in Pipe Diameter

Pipe diameter uncertainty based on manufacturer specified accuracy along with the standard deviation (S_D) of measurements taken in lab.

$$U_D = \sqrt{\left(\frac{S_D t}{\sqrt{n}}\right)^2 + U_{Caliper}^2}$$

In this case, t = 2.447 to correspond to the 6 data points were taken in lab to achieve a 95% confidence interval. As based on manufacture specifications, $\mu_{Caliper} = 0.02$.

$$U_D = \sqrt{\left(\frac{0.015 * 2.447}{\sqrt{6}}\right)^2 + 0.02_{Caliper}^2}$$

$$U_D = 0.025\ mm$$

Head Loss vs. Volumetric Flowrate

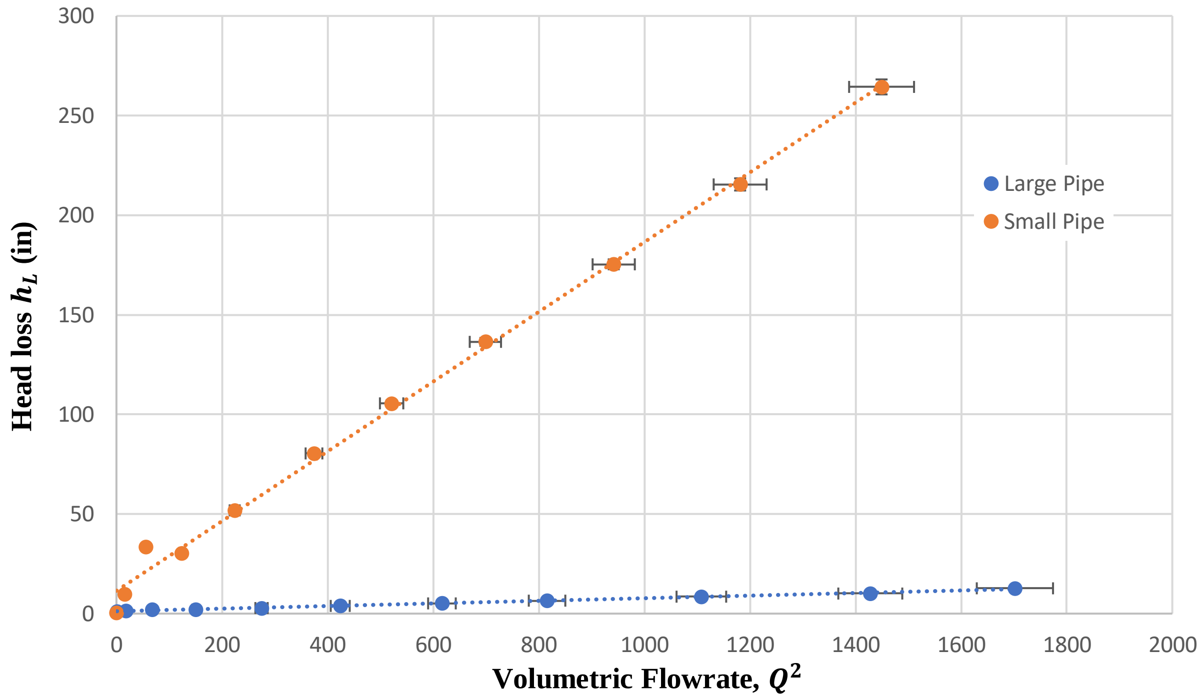


Figure 1: For both the large diameter pipe and the small diameter pipe, the plot links the head loss h_L to the volumetric flow rate squared Q^2. The data points for the small diameter pipe come from the single experiment run for such pipe. The data points for the large diameter pipe come from the last experiment run for such pipe. For both sets of data, the pipes show an increasing linear relationship between the two parameters. It can be noted that the small diameter pipe is affected by a larger head loss than the large diameter pipe. Uncertainty bars are included for both axes. Uncertainty bars are more noticeable for the volumetric flow rate squared as uncertainty is heavily increased when the volumetric flow rate is squared.

Head Loss Calculation

The equation for head loss h_L can be seen below. First the recorded pressure differential ΔP must be converted to metric units. Then, head loss is calculated using values of 997 kg/m^3 for the density of water and 9.806 m/s^2 for local gravity. This sample calculation is from data of the small pipe at a flowrate of 7.465 LPM.

$$h_L = \frac{\Delta P}{g\rho}$$

$$\Delta P\ [psi] * 6894.76 \frac{Pa}{psi} = \Delta P\ [Pa] = \Delta P\ \left[\frac{N}{m^2}\right] = \Delta P\ \left[\frac{kg}{ms^2}\right]$$

$$1.206\ \cancel{psi} * 6894.76\ \frac{Pa}{\cancel{psi}} = 8315.639\ \frac{N}{m^2}$$

$$h_L = \frac{8315.639 \frac{\cancel{kg}}{\cancel{m} \cdot \cancel{s^2}}}{9.806 \frac{\cancel{m}}{\cancel{s^2}} * 997 \frac{\cancel{kg}}{m^{\cancel{3}}}} = 0.850\ m$$

$$h_L = 0.850\ \cancel{m} * 39.37\ \frac{in}{\cancel{m}} = 33.486\ in$$

Uncertainty in Head Loss

$$U_{h_L} = \sqrt{\left(\frac{\partial h_L}{\partial \Delta P} U_{\Delta P}\right)^2 + \left(\frac{\partial h_L}{\partial g} U_g\right)^2 + \left(\frac{\partial h_L}{\partial \rho} U_\rho\right)^2}$$

$$\frac{\partial h_L}{\partial \Delta P} = \frac{1}{g\rho} = \frac{1}{\left(9.806 \frac{m}{s^2}\right)\left(997 \frac{kg}{m^3}\right)} = 1.023 \times 10^{-4} \frac{kg}{ms^2}$$

$$\frac{\partial h_L}{\partial g} = \frac{-\Delta P}{g^2 \rho}$$

$$\frac{\partial h_L}{\partial \rho} = \frac{-\Delta P}{g \rho^2}$$

$$U_{h_L} = \sqrt{\left(\frac{1}{g\rho} U_{\Delta P}\right)^2 + \left(\frac{-\Delta P}{g^2\rho} U_g\right)^2 + \left(\frac{-\Delta P}{g\rho^2} U_\rho\right)^2}$$

$$U_{h_L} = \sqrt{\left(\frac{55.757 \frac{\cancel{kg}}{\cancel{ms^2}}}{\left(9.806 \frac{\cancel{m}}{\cancel{s^2}}\right)\left(997 \frac{\cancel{kg}}{m^3}\right)}\right)^2 + \left(\frac{\left(-55.757 \frac{\cancel{kg}}{\cancel{ms^2}}\right)\left(9.806 \frac{\cancel{m}}{\cancel{s^2}}\right)}{\left(9.806 \frac{\cancel{m}}{\cancel{s^2}}\right)^2 \left(997 \frac{\cancel{kg}}{m^3}\right)}\right)^2 + \left(\frac{\left(-55.757 \frac{\cancel{kg}}{\cancel{ms^2}}\right)\left(997 \frac{\cancel{kg}}{\cancel{m^3}}\right)}{\left(9.806 \frac{\cancel{m}}{\cancel{s^2}}\right)\left(997 \frac{\cancel{kg}}{m^3}\right)^2}\right)}$$

$$U_{h_L} = 0.0133\ m * 39.37 \frac{in}{m} = 0.524\ in$$

Friction Factor vs. Reynolds Number

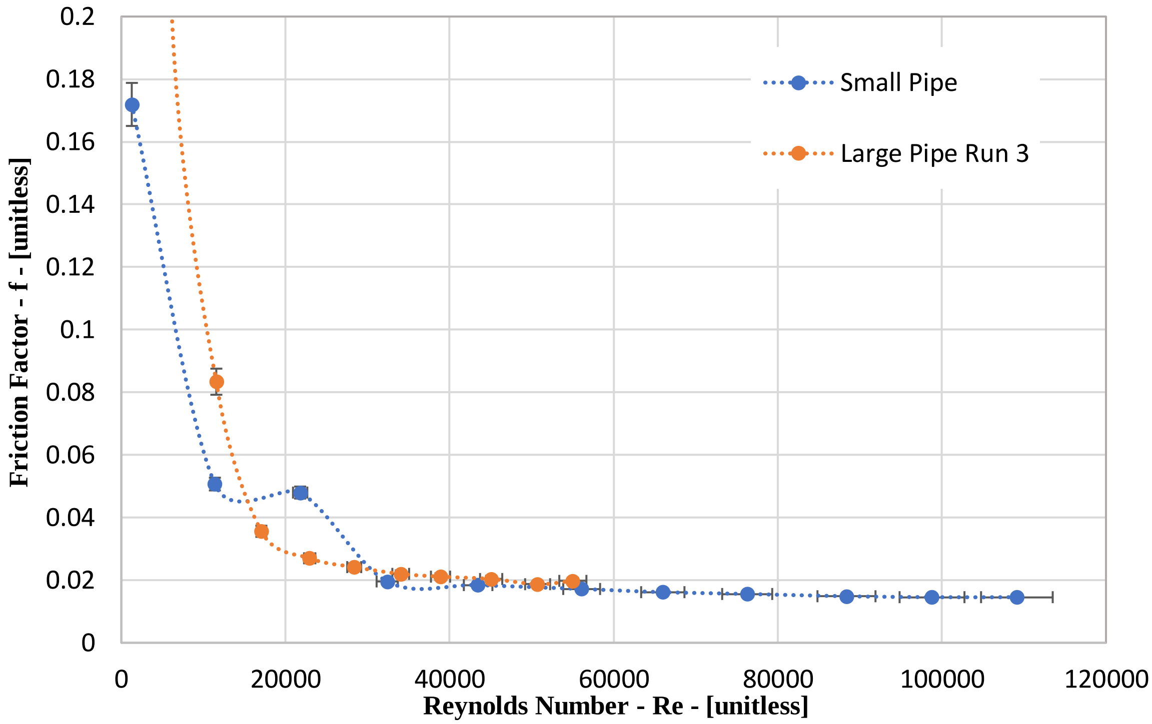


Figure 2: This plot demonstrates the relationship between Friction Factor and Reynolds number for both Large and Small Pipes as flow rate is decreased. Run 3 was chosen to portray large pipe behavior as it utilizes the same data collection method as the small pipe. This data sampling method – 200 samples/iteration, sampling rate 400 samples per second, run time 10 seconds – was the most accurate. The first data point for the Large Pipe was truncated from plot for visual's sake. The reason the point is off the chart is because flow rate for that data point was 0.877 Liters/min which caused the friction factor value to be 3.75.

Velocity Calculation

The equation for Velocity of the water through the pipe is below. Where $\dot{\forall}=$ $Volumetric\ Flow\ Rate$, *A=Area,* and *D=Diameter.*

$$V = \frac{\dot{\forall}}{A} = \frac{\dot{\forall}}{\pi\left(\frac{1}{2}D\right)^2}$$

This example is taken from data of the Large Pipe, Run 3 100% open (41.3 LPM nominal).

$$V = \frac{41.25\,\frac{\cancel{liters}}{\cancel{min}} * \frac{1m^3}{1000\,\cancel{liters}} * \frac{1\cancel{min}}{60sec}}{\pi\left(\frac{1}{2} * 18.8773\cancel{mm} * \frac{1m}{1000\cancel{mm}}\right)^2} = 2.454\,\frac{m}{s}$$

Reynolds Number Calculation

Below is the equation used to calculate Reynolds Number where $\rho = Density\ of\ water$, *V=Velocity, D=Diameter,* and $\mu = Dynamic\ Viscosity\ of\ water$.

$$Re = \frac{\rho V D}{\mu}$$

This example is taken from data of the Large Pipe, Run 3 100% open (41.3 LPM nominal).

$$Re = \frac{996.34\,\frac{\cancel{kg}}{\cancel{m^3}} * 2.454\,\frac{\cancel{m}}{\cancel{s}} * 18.8773\,\cancel{mm} * \frac{1\cancel{m}}{1000\cancel{mm}}}{0.0008509\,\frac{\cancel{N} * \cancel{s}}{\cancel{m^2}} * \frac{\cancel{kg} * \cancel{m}}{\cancel{s^2} * \cancel{N}}} = 5.433 \text{ x } 10^4$$

Friction Factor Calculation

Friction factor (*f*) is calculated below using $\Delta P = Pressure\ differential$, $\rho = Density$, *V=velocity, L=Length of Pipe,* and *D= Pipe Diameter.*

$$f = \frac{\Delta P}{\frac{1}{2}\rho V^2 \frac{L}{D}}$$

This example is taken from data of the Large Pipe, Run 3 100% open (41.3 LPM nominal).

$$f = \frac{0.457\,\frac{\cancel{lb}}{\cancel{in^2}} * 6894.76\,\frac{\cancel{N * in^2}}{\cancel{m^2 * lb}} * \frac{\cancel{kg * m}}{\cancel{s^2 * N}}}{\frac{1}{2} * 996.34\,\frac{\cancel{kg}}{\cancel{m^3}} * \left(2.454\,\frac{\cancel{m}}{s}\right)^2 * \frac{1000\cancel{mm}}{18.8773\cancel{mm}}} = 0.0198$$

Uncertainty in Reynolds Number

Uncertainty in Reynolds number is determined by using RSS method. The components that go into this calculation are velocity, density, diameter, and dynamic viscosity.

$$U_{Re} = \sqrt{\left(\frac{\partial Re}{\partial V}\right)^2 U_V^2 + \left(\frac{\partial Re}{\partial D}\right)^2 U_D^2 + \left(\frac{\partial Re}{\partial \mu}\right)^2 U_\mu^2 + \left(\frac{\partial Re}{\partial \rho}\right)^2 U_\rho^2}$$

This equation then becomes:

$$U_{Re} = \sqrt{\left(\frac{D\rho}{\mu}\right)^2 U_V^2 + \left(\frac{V\rho}{\mu}\right)^2 U_D^2 + \left(-\frac{DV\rho}{\mu^2}\right)^2 U_\mu^2 + \left(\frac{DV}{\mu}\right)^2 U_\rho^2}$$

For U_ρ & U_μ, uncertainty was chosen to be 0.1% of the value observed on the table to account for error. Uncertainty in Velocity, U_V is determined from this equation:

$$U_V = \sqrt{\left(\frac{\partial V}{\partial \dot{\forall}}\right)^2 U_{\dot{\forall}}^2 + \left(\frac{\partial V}{\partial D}\right)^2 U_D^2} = \sqrt{\left(\frac{1}{\pi\left(\frac{1}{2}D\right)^2}\right)^2 U_{\dot{\forall}}^2 + \left(-\frac{\dot{\forall}}{\pi\left(\frac{1}{2}D\right)^3}\right)^2 U_D^2} = 0.004\frac{m}{s}$$

This example is taken from data of the Large Pipe, Run 3 100% open (41.3 LPM nominal).

$$U_{Re} = \sqrt{\begin{array}{c}\left(\frac{0.018877 * 996340}{0.8509}\right)^2 0.004^2 + \left(\frac{2.454 * 996340}{0.8509}\right)^2 0.025^2 \\ +\left(-\frac{0.018877 * 2.454 * 996340}{0.8509^2}\right)^2 0.0008509^2 \\ + \left(\frac{0.018877 * 2.454}{0.8509}\right)^2 0.996^2\end{array}}$$

$$U_{Re} = 133.14$$

Uncertainty in Friction Factor

Uncertainty in friction factor is determined using RSS method. The components that go into this calculation are pressure differential, density, velocity, and diameter.

$$U_f = \sqrt{\left(\frac{\partial f}{\partial \Delta P}\right)^2 U_{\Delta P}^2 + \left(\frac{\partial f}{\partial \rho}\right)^2 U_\rho^2 + \left(\frac{\partial f}{\partial V}\right)^2 U_V^2 + \left(\frac{\partial f}{\partial D}\right)^2 U_D^2}$$

$$U_f = \sqrt{\left(\frac{1}{\frac{1}{2}\rho V^2 \frac{L}{D}}\right)^2 U_{\Delta P}^2 + \left(\frac{-\Delta P}{\frac{1}{2}\rho^2 V^2 \frac{L}{D}}\right)^2 U_\rho^2 + \left(\frac{-2\Delta P}{\frac{1}{2}\rho V^3 \frac{L}{D}}\right)^2 U_V^2 + \left(\frac{\Delta P}{\frac{1}{2}\rho V^2}\right)^2 U_D^2}$$

Example from Large Pipe, Run 3 100% open (41.3 Liters per minute nominal).

$$U_f = \sqrt{\begin{array}{c}\left(\frac{1}{\frac{1}{2} * 996340 * 2.454^2 * \frac{1}{0.01887}}\right)^2 94.4^2 + \left(\frac{-3147.46}{\frac{1}{2} * 996340^2 * 2.454^2 * \frac{1}{0.01887}}\right)^2 0.996^2 \\ + \left(\frac{-2 * 3147.46}{\frac{1}{2} * 996340 * 2.454^3 \frac{1}{0.01887}}\right)^2 0.004^2 + \left(\frac{3147.46}{\frac{1}{2} * 996340 * 2.454^2}\right)^2 0.025\hat{}2\end{array}}$$

$$U_f = 2.26 \times 10^{-4}$$

Table 5: Elbow – 200 samples/iteration, sampling rate 400 samples per second, run time 10 seconds.

Large pipe Nominal flowrate (LPM)	Actual flow rate (LPM)	Flowrate uncertainty (± LPM)	Head loss Δh (inches)	Standard deviation of head loss (inches)	Total uncertainty of head loss (± inches)	Temperature (°C)	Uncertainty in temp. (°C) (std dev + instrument error)
41.3	41.253	1.237	17.542	0.237	0.343	27.61	0.207
37.17	37.788	1.133	14.009	0.203	0.283	27.90	0.209
33.04	33.285	0.998	10.915	0.127	0.199	28.30	0.212
28.91	28.559	0.856	8.238	0.141	0.182	28.57	0.214
24.78	24.830	0.745	6.476	0.156	0.181	28.88	0.216
20.65	20.587	0.617	4.745	0.189	0.201	29.14	0.219
16.52	16.577	0.497	3.250	0.243	0.247	29.35	0.220
12.39	12.254	0.367	2.326	0.288	0.291	29.62	0.222
8.26	8.257	0.247	2.345	0.325	0.326	29.95	0.224
4.13	4.218	0.126	1.233	0.389	0.389	30.17	0.226
0	0.877	0.0263	0.702	0.374	0.374	30.16	0.226

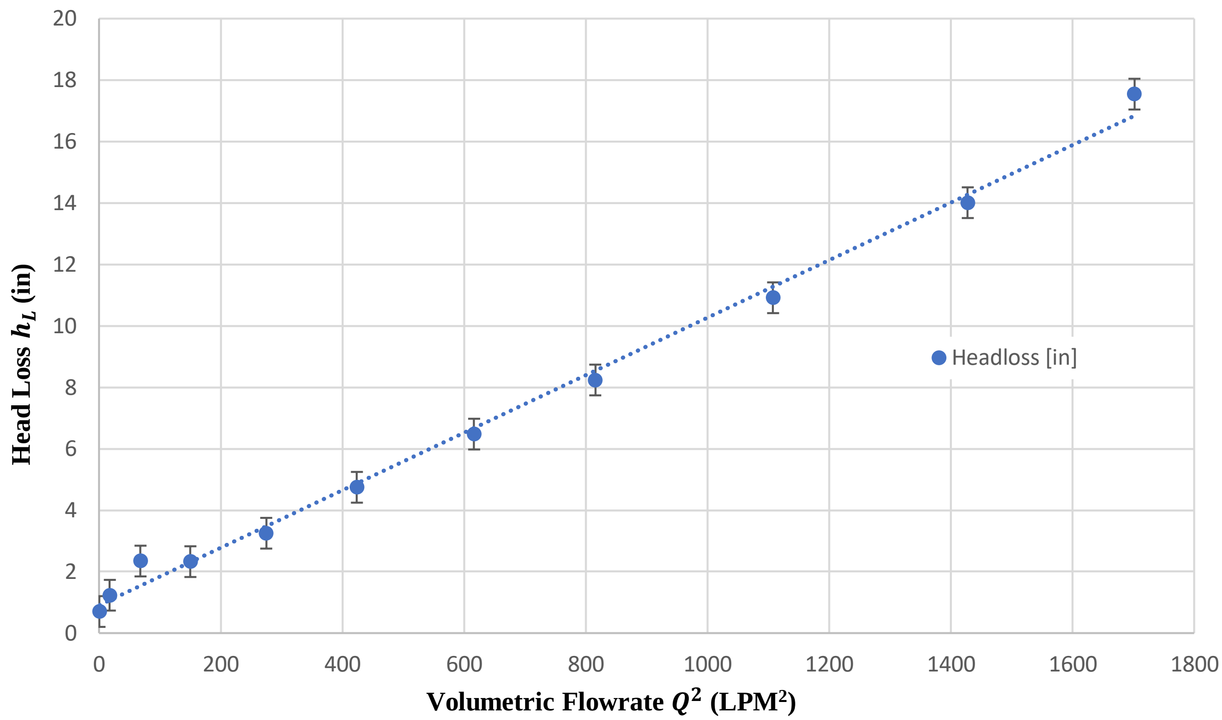


Figure 3: 90° elbow head loss data collected at different flow rates. The data was collected using the sampling method from run 3. The loss coefficient, K_L, can be calculated using the equation $K_L = h_L * \frac{2*g}{V^2}$, where h_L is the head loss, g is gravitational acceleration, and V^2 is the velocity of the flow. The slope is proportional to the loss coefficient when volumetric flow rate is maintained as a constant.

Loss Coefficient

The loss coefficient, K_L, can be found using the following equation.

$$K_L = \frac{2g * h_L}{V^2}$$

Where g is the gravitational acceleration, h_L is the head loss of the 90° elbow, and V is the flow velocity. An example of the calculation used to find the loss coefficient is as follows at a nominal flowrate of 20.587 liters per minute.

$$K_L = \frac{2 * 9.792\left(\frac{m}{s^2}\right) * 0.1205(m)}{(1.226(\frac{m}{s}))^2} = 1.5704$$

The uncertainty in the loss coefficient, U_{K_L}, can be found using the following equation.

$$U_{K_L} = \sqrt{\left(U_g * \frac{\partial K_L}{\partial g}\right)^2 + \left(U_{h_L} * \frac{\partial K_L}{\partial h_L}\right)^2 + \left(U_V * \frac{\partial K_L}{\partial V}\right)^2}$$

Where

$$\frac{\partial K_L}{\partial g} = \frac{2 * h_L}{V^2}$$

$$\frac{\partial K_L}{\partial h_L} = \frac{2 * g}{V^2}$$

$$\frac{\partial K_L}{\partial V} = \frac{-4 * g * h_L}{V^3}$$

After substituting the expressions above, the equation becomes:

$$U_{K_L} = \sqrt{\left(\frac{2 * h_L}{V^2} * U_g\right)^2 + \left(\frac{2 * g}{V^2} * U_{h_L}\right)^2 + \left(\frac{-4 * g * h_l}{V^3} * U_V\right)^2}$$

The uncertainty in gravity, head loss, and velocity are as follows.

$$U_g = 0.09792\frac{m}{s^2}, \qquad U_{h_L} = 0.0133\, m, \qquad U_V = 0.004\ \frac{m}{s}$$

The following uncertainty in the loss coefficient calculation was calculated using data collected at a nominal flowrate of 20.587 liters per minute.

$$U_{K_L} = \sqrt{\left(\frac{2 * 0.1205(\cancel{m})}{\left(1.226\left(\frac{\cancel{m}}{\cancel{s}}\right)\right)^2} * 0.09792\left(\frac{\cancel{m}}{\cancel{s^2}}\right)\right)^2 + \left(\frac{2 * 9.792\left(\frac{\cancel{m}}{\cancel{s^2}}\right)}{\left(1.226\left(\frac{\cancel{m}}{\cancel{s}}\right)\right)^2} * 0.0133(\cancel{m})\right)^2 + \left(\frac{-4 * 9.792\left(\frac{\cancel{m}}{\cancel{s^2}}\right) * 0.1205(\cancel{m})}{\left(1.226\left(\frac{\cancel{m}}{\cancel{s}}\right)\right)^3} * 0.004(\cancel{m})\right)^2} = 0.1743$$

Roughness Factor of the Large Diameter Pipe

For this section, the Colebrook equation comes into play which allows a representation of the roughness factor ϵ/D in terms of the Reynolds number and friction factor. Both the Reynolds number and the friction factor have been previously calculated in this report. The following sample calculation makes use of Reynolds number and friction factor from the last experiment run (Run 3) for the large diameter pipe at a volumetric flow rate of 16.6 LPM.

$$\frac{1}{\sqrt{f}} = -2.0 \log\left(\frac{\frac{\varepsilon}{D}}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

$$10^{-\frac{1}{2\sqrt{f}}} = \frac{\frac{\varepsilon}{D}}{3.7} + \frac{2.51}{Re\sqrt{f}}$$

$$\frac{\epsilon}{D} = 3.7\left(10^{-\frac{1}{2\sqrt{f}}} - \frac{2.51}{Re\sqrt{f}}\right)$$

$$Re = 22956, f = 0.02698$$

$$\frac{\epsilon}{D} = 3.7\left(10^{-\frac{1}{2\sqrt{0.02698}}} - \frac{2.51}{22956\sqrt{0.02698}}\right)$$

$$\frac{\epsilon}{D} = 8.82 \times 10^{-4}$$

As shown by the Moody diagram, the roughness of copper piping is $\epsilon_{Moody} = 0.0015\ mm$. As it is desired to compare the roughness factor provided by the Moody diagram to the experimental roughness factor, the standard roughness factor is equal to $\frac{\epsilon_{Moody}}{D} = \frac{0.0015\ mm}{18.877\ mm} = 7.94 \times 10^{-5}$. The experimental roughness factor is around 11 times greater than the roughness factor obtained from the Moody diagram. According to the experimental work, the piping in the laboratory is rougher than the standard copper piping used in industrial applications. Reasons why the experimental roughness is around an order of magnitude greater than the standard roughness factor can be the huge propagation of uncertainty associated with the Reynolds number and the friction factor, as well as the wear and tear caused by the long-term use of the equipment e.g., pipes, elbows, valves, etc. It is also noted that the roughness factor gets closer to the standard roughness factor the higher the volumetric flow rate becomes.

Uncertainty in Measured Parameters

Table 6: The table below provides equipment used to procure all measured data used in calculations, along with corresponding uncertainties.

Measurement	Equipment	Uncertainty	Units
Pressure Differential Large Pipe & Elbow	Omega PX409-001DWU5V	±0.014	$\frac{lb}{in^2}$
Pressure Differential Small Pipe	Omega PX409-015DDU5V	±0.018	$\frac{lb}{in^2}$
Pump Gage Pressure	Omega PX309-300G5V	±0.180	$\frac{lb}{in^2}$
Volumetric Flow Rate	Proteus 0270P24	±6.75	$\frac{Liters}{min}$
Volumetric Flow Rate	Proteus 0250BT	±1.35	$\frac{Liters}{min}$
Volumetric Flow Rate	Proteus 0205C24	±0.285	$\frac{Liters}{min}$
Water Temperature	Omega JMTSS-125G-6	±0.22	$°C$
Pipe Diameter	Mitutoyo Calipers	±0.025	mm

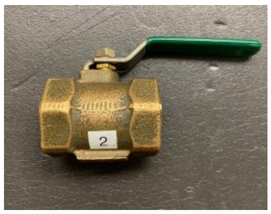
Table 7: The entrance length, l, for the Reynolds number was calculated for each run. The equation to calculate the entrance length differs based on the flow characteristic. For laminar flow $l = 0.05 * Re * D$ and for turbulent flow $l = 10 * D$. Laminar flow was a rare flow characteristic and occurred during the nominal flowrate of 0. The data values at the 0 nominal flowrate are worthless because there was no flow running through the system. For the majority of the flow, the entrance length for the large pipe is twice the length of the small pipe. Runs 1 through 3 have similar entrance lengths, this was to be expected because the sampling rate was the only variable being manipulated between those runs. With a pipe length of $1m$, the flow had enough distance to become fully developed.

Run Number	Nominal Flow Rate, *Q* (liter/min)	Reynolds Number, *Re*	Flow Characteristic	Entrance Length, *l* (*m*)
1 – Large Pipe	0	1250.601	Laminar	11.804
	4.13	5911.594	Turbulent	0.189
	8.26	11536.372	Turbulent	0.189
	12.39	17005.026	Turbulent	0.189
	16.52	22927.094	Turbulent	0.189
	20.65	28386.621	Turbulent	0.189
	24.78	33924.969	Turbulent	0.189
	28.91	38776.064	Turbulent	0.189
	33.04	44807.936	Turbulent	0.189
	37.17	49760.248	Turbulent	0.189
	41.3	54304.500	Turbulent	0.189
2 – Large Pipe	0	1249.717	Laminar	11.795
	4.13	5942.483	Turbulent	0.189
	8.26	11566.978	Turbulent	0.189
	12.39	17060.627	Turbulent	0.189
	16.52	23024.487	Turbulent	0.189
	20.65	28428.397	Turbulent	0.189
	24.78	34032.689	Turbulent	0.189
	28.91	38909.303	Turbulent	0.189
	33.04	45044.422	Turbulent	0.189
	37.17	50499.887	Turbulent	0.189
	41.3	54942.457	Turbulent	0.189
3 – Large Pipe	0	1236.356	Laminar	11.669
	4.13	5943.795	Turbulent	0.189
	8.26	11581.576	Turbulent	0.189
	12.39	17066.107	Turbulent	0.189
	16.52	22956.784	Turbulent	0.189
	20.65	28382.083	Turbulent	0.189
	24.78	34048.922	Turbulent	0.189
	28.91	38899.682	Turbulent	0.189
	33.04	45071.247	Turbulent	0.189
	37.17	50731.946	Turbulent	0.189
	41.3	55026.268	Turbulent	0.189
4 – Small Pipe	0	1288.004	Laminar	6.031
	3.8	11400.717	Turbulent	0.094
	7.6	21797.051	Turbulent	0.094
	11.4	32405.621	Turbulent	0.094
	15.2	43482.930	Turbulent	0.094
	19	56100.469	Turbulent	0.094
	22.8	65988.209	Turbulent	0.094
	26.6	76273.232	Turbulent	0.094
	30.4	88372.112	Turbulent	0.094
	34.2	98797.387	Turbulent	0.094
	38	109139.388	Turbulent	0.094

Large Pipe Data Sampling Method Discussion

Three experimental runs were conducted on the large pipe all with varying sample rates. Run 1 took 1 sample per iteration at 400 iterations per second and lasted 5 seconds. Run 2 took 200 samples per iteration at 400 iterations a second and lasted 5 seconds. Finally, run 3 took 200 samples per iteration at 400 iterations per second for 10 seconds. The first run collected the largest number of data points; however, it was the least accurate sampling method. While there was a high intake of data, the quality of that data was poor due to 1 sample taken per iteration. The difference between runs 2 and 3 was the sampling lengths. It was predicted that run 3 would be more accurate than run 2 because it collected twice as much data. This was proven correct and run 3 proved to have the highest accuracy. The different sampling methods in this experiment showed that a sampling method with a higher sample per iteration count and a longer sampling time will increase the accuracy of the measurement.

Table 8: Nine valves shown in the Thermal Sciences laboratory

Valve Number	Valve Picture	Valve Name	Loss Coefficient	Reference
1		Ball check valve	70	https://neutrium.net/fluid-flow/pressure-loss-from-fittings-excess-head-k-method/
2		Butterfly valve	Open - 0 Closed 5° - 0.24 Closed 10° - 0.52 Closed 20° - 1.54 Closed 40° - 10.8 Closed 60° - 118	https://powderprocess.net/Tools_html/Piping/Pressure_Drop_Key_Piping_Elements_K_Coefficient.html
3		Full port ball valve	0.07	https://www.plumbingsupply.com/ed-frictionlosses.html
4		Three-way ball valve	1.0	https://www.engineeringtoolbox.com/minor-loss-coefficients-pipes-d_626.html
5		Swing check valve	2.0	https://neutrium.net/fluid-flow/pressure-loss-from-fittings-excess-head-k-method/
6		Globe valve	7.8	https://www.plumbingsupply.com/ed-frictionlosses.html

7		Gate valve	Fully open – 0.17 3/4 Open – 0.9 1/2 Open – 4.5 1/4 Open - 24	https://neutrium.net/fluid-flow/pressure-loss-from-fittings-excess-head-k-method/
8		Needle valve	1.08	https://tameson.com/products/nls-012-g1-2inch-stainless-steel-needle-valve-ptfe-300-bar
9		3-Piece, Full-Port Threaded Ball Valve	70	https://www.macombgroup.com/2638034/product/flow-tek-fp3104-3-3-g-l

Lab Report Participation Log

Name	Date	Hours Worked	Description of Tasks Performed
Alli Porras	5/23/23	1	Setting up lab report with section headings, content descriptions, and formatted tables
David Reyes	5/30/23	1	Gathering lab data and formatting values from each run into Excel sheets
Conor Bowman, Alex Carr, David Reyes, and Alli Porras	5/31/23	2	Work through each run and calculate values for large/small pipe data in Excel
Conor Bowman, David Reyes, and Alli Porras	6/1/23	1	Met on Teams to split up work for the rest of the report and help each other understand calculations
Conor Bowman	6/1/23	2	Calculated friction factor & Reynolds Number for large & small pipe
Alex Carr	6/2/23	10	Elbow head loss and loss coefficient calculations, entrance length calculations and sampling method discussion
Conor Bowman	6/2/23	11	Finished Friction Factor vs Reynolds Number graph, finished sample calcs & uncertainty, measured uncertainty table, temperature uncertainty
David Reyes	6/2/23	5	Calculate head loss and roughness factor for three experiment runs of the large diameter pipe and its uncertainty
Alli Porras	6/2/23	6	Wrote and edited the business letter, finished sample calculations, formatted report, and edited/proofread to ensure consistency.
	Total Hours:	39	