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Gainesville, FL 32607
February 15, 2021

Caitlyn Simonds
University of Florida
201 Criser Hall PO Box 114000
Gainesville, FL 32611

Dear Ms. Simonds:

The main objective of this lab is to gather data on a pipe system to characterize the system. The values that are measured and used to characterize the pipe system are as follows: friction factors, head losses, pipe roughness, and the head loss and loss coefficient for the 90° elbow. These values were all measured and determined by incrementally decreasing the flowrate of the water through the large and small pipe and measuring the flowrate, temperature, and the change in pressure.

The pump of the pipe system propels the water throughout the horizontal pipes. Once a critical entry length value is reached by the flow of water, the water is then fully developed. This is based off the assumption that the pipe is of a constant diameter. As the water keeps flowing there are many different factors that affect its volumetric flow rate and its pressure along the pipe. The degenerative characteristics of this water flow are the friction factor which relates the pressure change to the geometry of the pipe and the fluid type that is flowing, the major head loss which is due to the viscous shear stress on the pipe wall, the minor head losses which is due to the elbow, and the roughness factor which is a material property of the pipe. Bernoulli's principle cannot be utilized since the flow is inviscid. The fluid is assumed to be incompressible, and the flow is through a horizontal pipe, so the potential energy is assumed to be zero. Measuring the change in pressure and dividing it by the specific gravity of water gives the head losses associated with the flow. The head losses are then plotted vs. the flowrate squared. From this graph the loss coefficient can be determined from its slope. Once this is calculated the friction factor can be determined by the change in pressure, density, length of pipe, velocity of the flow, and the diameter of the pipe. From the friction factor the roughness factor can be determined. Then the friction factor is plotted vs. the Reynolds number.

The piping system is comprised of 1-meter-long copper pipes connected to a pump with 4 different pressure transducers, 3 different flowmeters, and a thermocouple. The pressure transducers were placed on the 18.85mm diameter copper pipe, the 9.36 mm copper pipe, the 90° elbow, and on the pump. The 3 different flowmeters were placed along the pipe to record the flowrate. The flowrate was controlled by a valve to specify the wanted lpm of water. Empirical data was then recorded by turning on the pump, opening the flowrate valve to 100% capacity, and then inputting current run sampling rates into the LabVIEW VI. The VI recorded the data from each pressure transducer, thermocouple, and each of the flowmeters to output the difference in pressure, flowrate, and temperature. Four runs were used to record data. The 1st run measured 2 samples/iteration at a sampling rate of 800 samples/second for 5 seconds. The 2nd run measured 200 samples/iteration at a sampling rate of 400 samples/second for 5 seconds. The 3rd run measured 200 samples/iteration at a sampling rate of 400 samples/second for 10 seconds. The 4th run measured 200 samples/iteration at a sampling rate of 400 samples/second for 10 seconds. The first three runs were of the large copper pipe and the fourth run is of the small pipe. Each run records data from 100% to 0% flowrate. To reduce error, each run waited for the flow to develop before collecting data and the VI was checked to ensure that the correct sampling rates, time, and samples/second were selected. To ensure safety, lab goggles and close-toed shoes were always worn, and the next valve was always opened before the next one to avoid burning the pump.

The characterization of the pipe system was done successfully. The maximum head loss of the large and small pipes was 12.77 in ± 0.253 in and 259.5 in ± 1.175 in, the friction factor ranged from 0.02867 to 0.01584, the loss coefficient was 0.841, and the roughness factor of the large pipe was 0.00114. These results illustrate that the pipe endured major losses and the flow was impacted by the pipe roughness and the losses due to the viscous shear stress.

Sincerely,

Cyril Moran Nickolas Saavedra

"On my honor, I have neither given nor received unauthorized aid in doing this assignment."

Data Sheet for Frictional Losses in Piping Systems

Date: 02/09/2022

Time: 8:30 AM

Team Members: Cyril Moran

Nickolas Saavedra

Ambient Temperature (°C): 25

Ambient Pressure (mm Hg): 765.3

Inner diameter large pipe: 18.85 mm

Uncertainty large pipe: ± 0.185 mm

Inner diameter small pipe: 9.36 mm

Uncertainty small pipe: ± 3.77×10^{-3} mm

Experimental Data

Table 1: Large Pipe - Run 1 – 2 sample/iteration, sampling rate 800 samples per second, run time 5 seconds.

***Large* pipe Nominal flowrate (LPM)**	**Actual flow rate (LPM)**	**Flowrate uncertainty (± LPM)**	**Pressure loss ΔP (psi)**	**Head loss Δh (inches)**	**Standard deviation of head loss (inches)**	**Total uncertainty of head loss (± inches)**	**Temperature (°C)**	**Uncertainty in temperature (°C) (std dev + instrument error)**
48.0	47.65	1.46	0.48	13.47	6.147	13.56	26.32	0.508
43.2	42.36	1.28	0.42	11.85	3.057	6.643	27.68	0.507
38.4	38.40	1.16	0.31	8.493	7.522	16.32	27.85	0.522
33.6	31.50	0.945	0.28	7.917	6.453	14.35	28.69	0.508
28.8	28.80	0.864	0.22	6.189	5.868	13.45	29.03	0.502
24.0	24.69	0.743	0.12	3.463	6.353	13.82	29.71	0.514
19.2	20.02	0.601	0.14	3.783	6.424	13.98	29.89	0.516
14.4	16.10	0.484	0.10	2.672	11.83	24.72	30.50	0.551
9.6	8.252	0.249	0.02	0.6598	5.225	11.62	31.47	0.508
4.8	4.511	0.135	-0.02	-0.4481	5.690	12.56	31.12	0.535

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)**	**Pressure loss ΔP (psi)**	**Head loss Δh (inches)**	**Standard deviation of head loss (inches)**	**Total uncertainty of head loss (± inches)**	**Temperature (°C)**	**Uncertainty in temperature (°C) (std dev + instrument error)**
48.0	46.19	1.39	0.47	12.97	0.1389	0.3067	27.23	0.502
43.2	42.61	1.28	0.400	11.14	0.0616	0.1345	27.57	0.517
38.4	38.44	1.16	0.340	9.312	0.0745	0.1632	28.01	0.528
33.6	31.44	0.945	0.240	6.692	0.1098	0.2422	28.56	0.518
28.8	28.92	0.871	0.210	5.789	0.0677	0.1453	29.12	0.519
24.0	24.63	0.740	0.160	4.347	0.1148	0.2529	29.56	0.511
19.2	20.02	0.601	0.110	3.071	0.1232	0.2708	29.95	0.513
14.4	16.05	0.482	0.070	2.214	0.4409	0.9148	30.37	0.512
9.6	8.27	0.248	0.020	0.5384	0.0625	0.1363	31.38	0.502
4.8	4.38	0.132	0.004	0.1289	0.0432	0.0965	31.58	0.502

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)	Pressure loss ΔP (psi)	Head loss Δh (inches)	Standard deviation of head loss (inches)	Total uncertainty of head loss (± inches)	Temperature (°C)	Uncertainty in temperature (°C) (std dev + instrument error)
48.0	46.05	1.39	0.46	12.77	0.0788	0.2526	27.33	0.502
43.2	42.47	1.28	0.40	11.15	0.1241	0.2775	27.46	0.517
38.4	38.56	1.16	0.34	9.305	0.0589	0.1316	28.13	0.518
33.6	31.43	0.944	0.24	6.782	0.0889	0.2175	28.45	0.512
28.8	28.81	0.867	0.21	5.886	0.1234	0.2989	29.25	0.502
24.0	24.61	0.740	0.16	4.425	0.1018	0.2257	29.45	0.507
19.2	20.06	0.603	0.11	4.381	0.2437	0.4170	30.03	0.533
14.4	15.95	0.481	0.05	1.575	0.3044	0.6762	30.24	0.525
9.60	8.31	0.249	0.02	0.5098	0.0604	0.1345	31.19	0.519
4.80	4.38	0.132	0.01	0.1542	0.0503	0.1094	31.78	0.506

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

Small pipe **Nominal flowrate (LPM)**	**Actual flow rate (LPM)**	**Flowrate uncertainty (± LPM)**	**Pressure loss ΔP (psi)**	**Head loss** **Δh (inches)**	**Standard deviation of head loss (inches)**	**Total uncertainty of head loss** **(± inches)**	**Temperature (°C)**	**Uncertainty in temperature (°C) (std dev + instrument error)**
48	43.11	1.428	9.34	259.5	0.3957	1.175	32.17	0.522
43.2	41.16	1.497	8.59	238.2	0.5035	1.309	32.42	0.522
38.4	35.09	1.087	6.65	184.9	0.4938	1.104	32.59	0.508
33.6	32.23	1.012	5.78	160.6	0.4107	0.9201	32.72	0.535
28.8	29.43	0.928	4.99	138.7	0.3027	0.6713	32.83	0.518
24.0	26.38	0.831	4.18	116.2	0.2191	0.4907	32.99	0.503
19.2	20.21	0.656	2.59	71.82	0.3170	0.7415	33.14	0.518
14.4	16.94	0.553	1.93	53.57	0.1612	0.3608	33.21	0.508
9.6	9.13	0.307	0.603	16.02	3.298	3.304	33.39	0.515
4.8	4.51	0.139	0.150	4.169	0.0748	0.1614	33.35	0.516

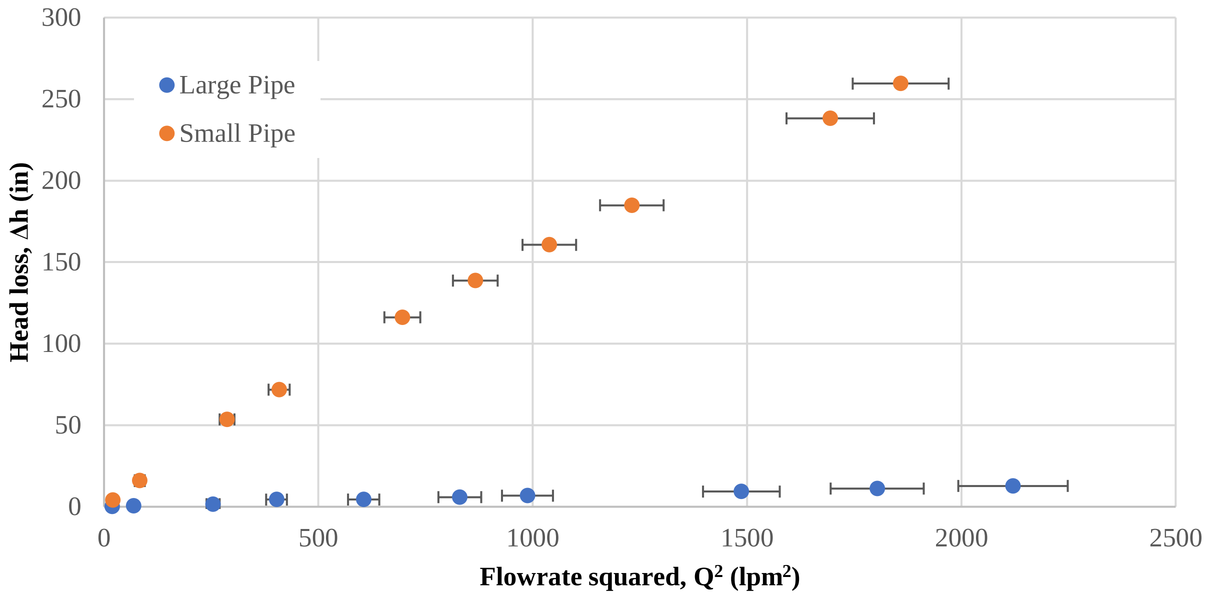

Figure 1: The head loss was calculated using the change in pressure at different flow rates and plotted vs. the flowrate squared. The flowrate was measured using a Proteus© 200 Series Flowmeter (3% accuracy), and the change in pressure was measured using the Omega© Pressure Transducer. The linear profile depicted illustrates how the head loss increases at a constant rate for the respective flowrate. The slope of the graph can be determined to find the relationship between head loss and flowrate squared. A sampling rate of 200 measurements per iteration at 400 measurements per iteration was used, where each data point on the graph is the average of each iteration. The uncertainty bars for the head loss are present in the graph but they are small compared to the x-axis bounds.

The sample calculations will be of the third run for the large pipe showcasing a sampling rate of 200 samples per iteration, 400 samples per second, and a run time of 10 seconds. The density of water ρ at a temperature of 25 ^{o}C is found to be 996.53 kg/m^3 . In the following equation ΔP is the pressure loss, g is the gravitational constant, ρ is the density of water, and Δh is the resulting head loss.

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

$$\Delta h = \frac{3170.07\ \frac{N}{m^2}}{\left(996.53\ \frac{kg}{m^3}\right)\left(9.81\ \frac{m}{s^2}\right)}$$

$$\Delta h = \frac{3170.07\ \frac{kg \cdot m}{s^2 \cdot m^2}}{9775.96\ \frac{kg \cdot m}{m^3 \cdot s^2}}$$

$$\Delta h = 0.3243\ m$$

$$\Delta h = 12.77\ in$$

To determine the uncertainty showcased in the head loss, the following equation was used. In the following uncertainty calculations U(Δh) represents the uncertainty in the head loss, Δh(B_x) represents the root sum squared method of the head loss equation uncertainties, Δh(P_x) represents the standard deviation of the head loss, U(ΔP) is the uncertainty in the pressure loss, U(ρ) is the uncertainty in the density of the fluid, ρ is the density of the fluid, g is the gravitational constant, and ΔP is the pressure loss.

$$U(\Delta h) = \sqrt{\Delta h(B_x)^2 + \Delta h(P_x)^2}$$

$$B_x = \sqrt{\left(\frac{\partial \Delta h}{\partial \Delta P} \cdot U(\Delta P)\right)^2 + \left(\frac{\partial \Delta h}{\partial P} \cdot U(\rho)\right)^2}$$

$$B_x = \sqrt{\left(\frac{1}{\rho \cdot g} \cdot U(\Delta P)\right)^2 + \left(\frac{\rho \Delta P}{\rho^2 g} \cdot U(\rho)\right)^2}$$

$$B_x = \sqrt{\left(\left(\frac{1}{\left(996.53\ \frac{kg}{m^3}\right) \cdot \left(9.81 \frac{m}{s^2}\right)}\right) \cdot (39.12\ Pa)\right)^2 + \left(\frac{\left(996.53\ \frac{kg}{m^3}\right) \cdot (3170.07\ Pa)}{\left(996.53\ \frac{kg}{m^3}\right)^2 \cdot \left(9.81 \frac{m}{s^2}\right)} \cdot \left(0.0141 \frac{kg}{m^3}\right)\right)^2}$$

$$U(\Delta h) = \sqrt{B_x^2 + P_x^2} = \sqrt{0.2399^2 + 0.0788^2}$$

$$U(\Delta h) = 0.2526\ in$$

In the following equation Q is the flowrate, $U(Q)$ is the uncertainty in Q, $Q(P_x)$ is the standard deviation of Q, and $Q(B_x)$ is the accuracy in the measurement of Q.

$$U(Q) = \sqrt{Q(B_x)^2 + Q(P_x)^2}$$

$$U(Q) = \sqrt{\left(\left(0.000767\ \frac{m^3}{s}\right) \cdot 0.03\right)^2 + \left(2.728\ x\ 10^{-6}\frac{m^3}{s}\right)^2}$$

$$U(Q) = 2.3189\ x\ 10^{-5}\ \frac{m^3}{s}$$

$$U(Q) = 2.7796\ lpm$$

For the flowrate squared, the propagation of uncertainty is illustrated below. $U(Q^2)$ is the uncertainty in the flowrate squared, Q is the flowrate, and $U(Q)$ is the uncertainty in the flowrate.

$$U(Q^2) = 2 \cdot \frac{U(Q)}{Q}$$

$$U(Q^2) = 2 \cdot \frac{2.3189\ x\ 10^{-5}\ \cancel{\frac{m^3}{s}}}{0.000767\ \cancel{\frac{m^3}{s}}}$$

$$U(Q^2) = \ 6.046\%$$

$$U(Q^2) = 4.6378\ x\ 10^{-5}\ \frac{m^2}{s^2}$$

$$U(Q^2) = 128.044\ lpm^2$$

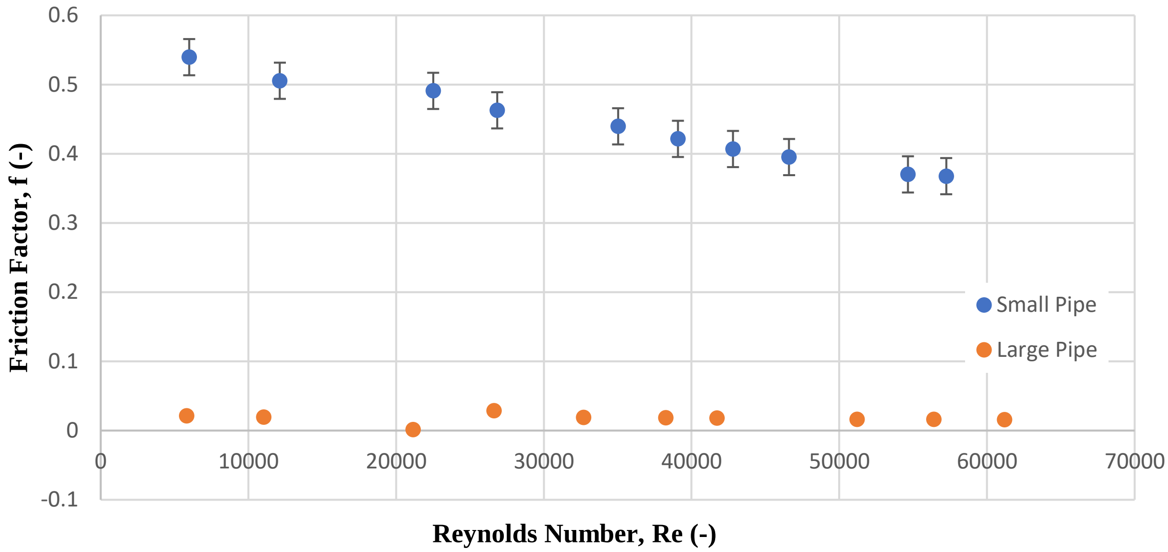

Figure *2*: The figure above showcases the friction factor versus the Reynolds number. As the Reynolds number increases, the small pipe experiences a lower friction factor. For the large pipe, the friction factor seems to relatively stay the same as the Reynolds number increases.

To determine the friction factor, the Reynolds number will need to be determined first to find whether the flow is turbulent or laminar. To calculate the Reynolds number, the average velocity of the fluid must be calculated first.

In the following equation V_{avg} is the average velocity of the flow, Q is the volumetric flowrate, and A_c is the cross-sectional area of the large copper pipe

$$V_{avg} = \frac{Q}{A_c}$$

$$V_{avg} = \frac{\left(0.000767\,\frac{m^3}{s}\right)}{0.000279\,m^2}$$

$$V_{avg} = 2.75271\ \frac{m}{s}$$

In the following calculation, Re is the Reynolds number, ρ is the density of the fluid, V_{ave} is the average velocity of the fluid, D is the inner diameter of the large copper pipe, and μ is the dynamic viscosity of the fluid.

$$Re = \frac{\rho \cdot V_{avg} \cdot D}{\mu}$$

$$Re = \frac{\left(996.53\,\frac{kg}{m^3}\right)\left(2.75275\,\frac{m}{s}\right)(0.01885\,m)}{0.0008446\,\frac{N \cdot s}{m^2}}$$

$$Re = \frac{51.7093\,\frac{kg \cdot m^2}{m^3 \cdot s}}{0.0004886\,\frac{kg \cdot s \cdot m}{s^2 \cdot m^2}}$$

$$Re = 61123.4$$

In the following calculation, f is the friction factor, *Δh* is the head loss, *D* is the inner diameter of the large copper pipe, *L* is the length of the large copper pipe, and V_{avg} is the average velocity of the fluid.

$$f = \frac{\Delta \mathrm{P}}{\frac{1}{2} \cdot V_{avg}^2 \cdot \frac{L}{D}}$$

$$f = \frac{2 \cdot \Delta \mathrm{h} \cdot \mathrm{D} \cdot \mathrm{g}}{L \cdot V_{avg}^2}$$

$$f = \frac{2 \cdot (0.32444\ \mathrm{m}) \cdot (0.01885\ \mathrm{m}) \cdot \left(9.81\ \frac{\mathrm{m}}{\mathrm{s}^2}\right)}{(1.0\ m) \cdot \left(2.7513\ \frac{m}{s}\right)^2}$$

$$f = \frac{0.11998\ \frac{\cancel{m^3}}{\cancel{s^2}}}{7.569\ \frac{\cancel{m^3}}{\cancel{s^2}}}$$

$$f = 0.01585$$

In the following calculation K_L is the loss coefficient for the 90° elbow, Δh is the head loss, V_{avg} is the average velocity of the flow, and g is the gravitational constant. The following values are of Run 3 at maximum flowrate.

$$K_L = \frac{\Delta h}{\frac{V_{avg}^2}{2 \cdot g}} \qquad \textit{Bergman, p. 339, Eqn. 8.36}$$

$$K_L = \frac{0.324\ m}{\frac{\left(2.75\ \frac{m}{s}\right)^2}{2 \cdot \left(9.81\ \frac{m}{s^2}\right)}}$$

$$K_L = \frac{0.324\ m}{\left(0.385\ \frac{\frac{m^{\cancel{2}}}{\cancel{s^2}}}{\frac{\cancel{m}}{\cancel{s^2}}}\right)}$$

$$K_L = 0.841\ \frac{\cancel{m}}{\cancel{m}}$$

$$K_L = 0.841$$

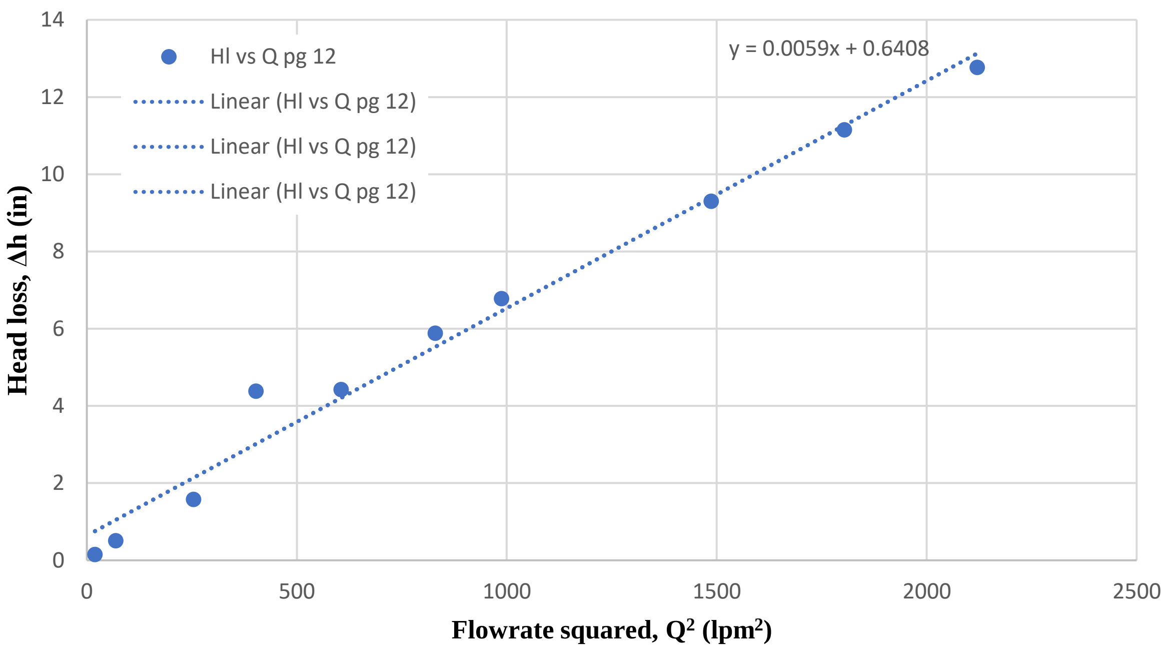

Figure *X*: The slope of figure x showcases that as the flowrate squared increases, the head loss increases. This indicates that the higher the flowrate, the greater the head losses are. The head losses showcase a linear a relationship with the squared flowrate. The slope is a representation of $\frac{k_L}{2g}V_{avg}^2$ where $Q^2 = V_{avg}^2 A^2$. This means that $0.0059 = \frac{K_L}{2g}V_{avg}^2$, and $x = Q^2$.

In the following uncertainty equations K_L is the loss coefficient, U(K_L) is the uncertainty in K_L, B_x is the bias error, P_x is the precision error (standard deviation of K_L), Δh is the head loss, V_{avg} is the average velocity of the flow, g is the gravitational constant, $U(h_L)$ is the uncertainty in the head loss, and $U(V_{avg})$ is the uncertainty in the average velocity.

$$K_L = \frac{\Delta h}{\frac{V_{avg}^2}{2 \cdot g}}$$

$$U(K_L) = \sqrt{B_x^2 + P_x^2}$$

$$B_x = \sqrt{\left(\frac{\partial K_L}{\partial \Delta h} \cdot U(\Delta h)\right)^2 + \left(\frac{\partial K_L}{\partial V_{avg}} \cdot U\left(V_{avg}\right)\right)^2}$$

$$B_x = \sqrt{\left(\frac{1}{\frac{\left(2.75\ \frac{\cancel{m}}{\cancel{s}}\right)^2}{2 \cdot \left(9.81\ \frac{\cancel{m}}{\cancel{s^2}}\right)}} \cdot (0.2525\ \cancel{m})\right)^2 + \left(\frac{\left(2.75\ \frac{\cancel{m}}{\cancel{s}}\right)^2 \cdot (0.3244\ \cancel{m})}{\frac{\left(2.75\ \frac{\cancel{m}}{\cancel{s}}\right)^3}{2 \cdot \left(9.81\ \frac{\cancel{m}}{\cancel{s^2}}\right)}} \cdot \left(0.0836\ \frac{\cancel{m}}{\cancel{s}}\right)\right)^2}$$

$$B_K = 0.1942$$

$$U(K_L) = \sqrt{0.1942^2 + 0.00835^2}$$

$$U(K_L) = 0.1944$$

The roughness factor for the large copper pipe was solved for by plotting two graphs. The x-coordinate of the intersection of the two graphs is the roughness factor of the pipe. This calculation is for Run 3 at 100% maximum flowrate.

In the following calculation *f* is the friction factor, *Re* is the Reynolds number, $\frac{\epsilon}{D}$ is the roughness factor of the pipe, y_1 is the graph of the left side of the equation, and y_2 is the graph of the right side of the equation.

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\frac{\epsilon}{D}}{3.7} + \frac{2.51}{Re\cdot\sqrt{f}}\right) \textit{Bergman, p. 337, Eqn. 8.35}$$

$$\frac{1}{\sqrt{0.019234}} = -2\log\left(\frac{\frac{\epsilon}{D}}{3.7} + \frac{2.51}{32681.53\cdot\sqrt{0.019234}}\right)$$

$$7.2105 = -2\log\left(\frac{\frac{\epsilon}{D}}{3.7} + 0.0005537\right)$$

$$y_1 = 7.2105$$

$$y_2 = -2\log\left(\frac{\frac{\epsilon}{D}}{3.7} + 0.0005537\right)$$

$$y_1 \cap y_2 = (0.00114, 7.2105)$$

$$\frac{\epsilon}{D} = 0.00114$$

The relative roughness calculated for the large copper pipe used for testing was found to be 0.00114. The standard range of relative roughness for average copper pipes of 0.01885 m diameter is 7.95 x 10^{-5} to 2 x 10^{-3}. The calculated value is in the middle of this range which illustrates that the relative roughness calculated in our experiment is consistent with industry values. An explanation for the relatively high calculated relative roughness compared to the industry standard minimum value is that the copper pipes used for testing are old and have been used constantly for a long time. This consistent usage of the pipes will cause it to become worn down which will increase then absolute roughness which will ultimately increase the relative roughness since the diameter stays approximately the same. The industry standard values for relative roughness include new copper pipes which would have small relative roughness values compared to older pipes such as the one used for the collection of data in this report.

Table 6: The uncertainties in all of the measured and recorded parameters for flowrates ranging from 46.05 lpm to 4.38 lpm are tabulated below. The flowrate uncertainty is the difference between the actual flowrate and the measured flowrate. The uncertainty is the accuracy of the flowmeter (3%), and the standard deviation of the measured values combined using RSS. The pressure loss uncertainty is twice the standard deviation of the measured values. The large pipe and small pipe diameter uncertainties are the standard deviation of the measured values (95% confidence interval) and the precision of the calipers (± 0.02 mm) combined using RSS. The large pipe and small pipe length uncertainties are one half of the resolution of the measuring device (±0.5 mm). The temperature uncertainty is the standard deviation of the temperature values added to the uncertainty of the resolution (± 0.5 °C) of the thermocouple.

Actual flowrate, Q (lpm)	**Flowrate uncertainty, U(Q) (±lpm)**	**Pressure loss uncertainty, U(ΔP) (±psi)**	**Large pipe diameter uncertainty, U(D) (±in)**	**Small pipe diameter uncertainty, $U(D_S)$ (±in)**	**Large pipe length uncertainty, U(L) (±in)**	**Small pipe length uncertainty, $U(L_S)$ (±in)**	**Temperature uncertainty, U(T) (°C)**
46.05	1.39	0.00567	0.00728	1.48×10^{-4}	0.0197	0.0197	0.502
42.47	1.28	0.00938	0.00728	1.48×10^{-4}	0.0197	0.0197	0.517
38.56	1.16	0.00425	0.00728	1.48×10^{-4}	0.0197	0.0197	0.518
31.43	0.944	0.00639	0.00728	1.48×10^{-4}	0.0197	0.0197	0.512
28.81	0.867	0.00889	0.00728	1.48×10^{-4}	0.0197	0.0197	0.502
24.61	0.740	0.00733	0.00728	1.48×10^{-4}	0.0197	0.0197	0.507
20.06	0.603	0.01226	0.00728	1.48×10^{-4}	0.0197	0.0197	0.533
15.95	0.481	0.02191	0.00728	1.48×10^{-4}	0.0197	0.0197	0.525
8.31	0.249	0.00435	0.00728	1.48×10^{-4}	0.0197	0.0197	0.519
4.38	0.132	0.00362	0.00728	1.48×10^{-4}	0.0197	0.0197	.0506

Table 7: The ratio of the pipes entrance length to the inner diameter of the pipe is the entrance length. This is a dimensionless value, and it decreases as the flowrate decreases. These values are not important because the pressure drop, flowrate, and temperature were all calculated at the end of the pipe which means that the flow has fully developed pressure and velocity profiles. The measurements were taken of the fully develop region of the pipe mean that the measurements from the VI are accurate. The entrance length for the maximum flowrate was 27.621. Using the diameter of the pipe, the entrance region is determined to be 0.52 m. The pipe is 1.0 m in length, so the flow becomes fully developed after it has traveled 52% the length of the pipe. This supports the assertion above that this quantity isn't critical since the measurements are taken at the end of the pipe (~ 1.0 m) so given the pipes diameter, the flow is developed by the time measurements are taken. These values are of Run 3.

Flowrate, Q (lpm)	**Entrance length, l/D**
46.05	27.621
42.47	27.249
38.56	26.813
31.43	25.914
28.81	25.540
24.61	24.849
20.06	24.045
15.95	23.139
8.31	20.762
4.38	18.662

The calculated values for run 1, run 2, and run 3 were significantly different from one another in terms of the derived uncertainty or validity of the results. Run 1 had a sampling rate of 2 samples/iteration at 800 samples/sec for 5 seconds. The data from this run produced a maximum head loss of 13.47 inches with an associated uncertainty of 13.56 inches. Run 1 produced uncertainties of over 100% for almost all calculated head loss values. Run 2 had a sampling rate of 200 samples/iteration at 400 samples/second for 5 seconds. The calculated head loss from run 2 (at 100% flowrate) was 12.97 inches with an associated uncertainty of 0.3067 inches. Run 2 had an uncertainty value of about 2.5% for all the calculated head loss values. Run 3 had a sampling rate of 200 samples/iteration at 400 samples/second for 10 seconds. The calculated head loss was 12.77 inches with an associated uncertainty value of 0.2526 inches. On average run 3 produced head loss values that had an uncertainty of about 1.9%. The run and sampling procedure that had the lowest uncertainty values was run 3. These results elucidate that an increase in samples/iteration, a reduction in samples/second, and an increase in the run time will result in less uncertainty. Run 1 produced uncertainty values that were over 95% more uncertain than the values from runs 2 and 3. This is a result of the high samples/second data collection and the low samples/iteration value of 2. The measured values have a high standard deviation that dominate the uncertainty propagation and result in these high values. Run 3 produced uncertainty results that were approximately 0.6% more accurate than run 2. Run 3 had the same samples/second and samples/iteration than run 2 but it ran for 10 seconds rather than 5 seconds. This produced more results for the run 3 data and by increasing the sample size of the data, the standard deviation decreased which resulted in a lower uncertainty value than run 2.

Valve Number	Valve Type	Loss Coefficient	References
1	True Union Ball Check Valve	11	TC_Cut_Sheet.pdf (alscoplastics.com)
2	Butterball Bronze Butterfly Disc Valve	43	BB2Series.pdf (milwaukeevalve.com)
3	Brass Ball Valve	49.71	Bonomi Group :: Rubinetterie Bresciane :: Valpres :: Valbia :: Univers (bonominorthamerica.com)
4	Brass Ball Valve	20	Cw617n Brass Ball Valve | UNI EN 12165 CZ122 Solenoid Valves (oshwin.com)
5	Low Pressure Flow Control Valve		Low Pressure Water Brass Flow Control Valve, Rs 135 /piece Flow Care Industries | ID: 22929467533 (indiamart.com)
6	Globe Valve		8108_Nibco_N53XA16_Specification_Sheet.pdf (firstsupply.com)
7	Gate Valve	54	105 - Milwaukee Valve
8	Needle Valve	0.76	Part Number 504-MFC, 1/2" National Pipe Thread (NPT), Male x Female, Steel, Soft Seat, 0.187" Orifice Needle Valve On NOSHOK, Inc.
9	Ball valve	55	3/4 THRD 3PC SS FP METAL SEAT, 2200 WOG, CF8M BODY, CF8M CHROME CARBIDE BALL AND SEAT, 17-4PH STEM, GRAPHITE STEM SEAL BALL VALVE W/LOCKING LEVER (macombgroup.com)

Lab Report Participation Log

Name	Date	Hours Worked	Description of Tasks Performed
Cyril Moran	02/14/2022	4	Wrote the letter
Cyril Moran	02/15/2022	4	Uploaded all the data to the tables on pages 2-4
Cyril Moran	02/16/2022	8	Created the graph for Δh vs. Q^2
Cyril Moran	02/18/2022	4	Wrote the sample calculations for K_L
Nickolas Saavedra	2/18/2022	4	Wrote sample calculations for head loss and uncertainty.
Nickolas Saavedra	2/21/2022	4	Wrote sample calculations for friction factor and Reynolds number
Cyril Moran	02/21/2022	8	Wrote the sample calculations for Δh and Re.
Cyril Moran	02/22/2022	10	Wrote the uncertainties for Δh and Re
Nickolas Saavedra	02/22/2022	11	Created friction factor vs. Reynolds number graph, Updated head loss vs. flowrate^2 graph. Identified valves. Formatted report
	Total Hours:	57	