Laboratory 4: Pipe Loss

Emily Fusselman, Willow Hoins, Hope Redhead, Anna Klein

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Introduction:

The objective of this lab is to explore how flow rates and pipe configurations affect pressure losses in pipe systems. We will examine the relationship between the Reynolds number, friction factor, and surface roughness, and how these factors contribute to major and minor pressure losses, as described by the Darcy-Weisbach equation and minor loss coefficients. Our approach involves measuring pressure drops across various pipe fittings at different flow rates to determine the friction factor for airflow bench pipes and the minor loss coefficients for round elbows and capped T-joints.

The theory we will apply includes the concepts of laminar and turbulent flow, the calculation of the Reynolds number to predict flow patterns, and the use of Moody's diagram to relate the friction factor to pressure losses. Major losses are calculated using the Darcy-Weisbach equation, while minor losses are determined using empirically derived minor loss coefficients.

Our hypothesis is that increased flow rates will lead to higher pressure losses due to enhanced frictional forces and flow disruptions, especially in turbulent flow regimes and at pipe fittings. We expect the experiments to confirm that both major and minor losses will scale with flow rate, with minor losses being particularly significant at higher flow rates due to the presence of fittings like elbows and T-joints.

Methods:

Lab Setup:

The experimental setup consists of an airflow bench with a schematic representation as shown in Figure 1. The system includes various pipe sections and fittings, such as a round elbow and capped T-joints, which are used to study pressure losses. The setup is equipped with an electronic manometer for pressure measurements and a laminar flow meter for flow rate determination.

Schematic of experimental piping system:

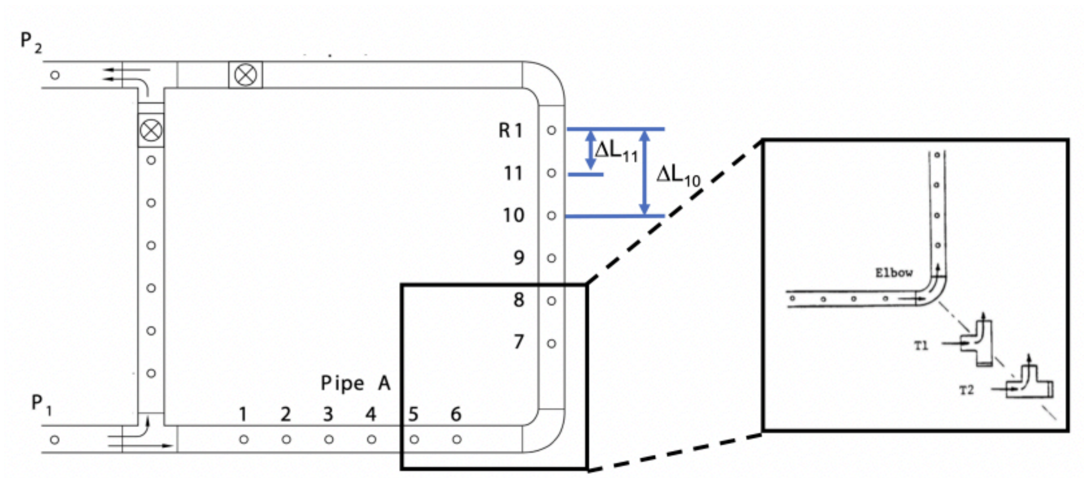

Figure 1: *Schematic of experimental piping system. Note that pipe B will not be used in this experiment.*

Experimental Process:

We initiated the experiment by ensuring the gate and ball valves were fully open. With the airflow bench system off, we activated the electric manometer, setting the low pressure (LP) switch to R1 and the high pressure (HP) switch to A, corresponding to pipe A. After zeroing the manometer, we turned the system on and allowed it to stabilize with the round elbow in place. During this warm-up phase, we recorded the barometric pressure, the inside diameters of the pipe, elbow, and capped T, as well as the distance between adjacent taps along pipe A, starting from R1.

We then proceeded to adjust the flow rate using the gate valve beneath the table, aiming for a flow rate of 40 mm H2O as indicated by the laminar flow meter and inclined manometer. We meticulously recorded the temperature of the flow from the electronic display of the thermocouple unit. For our measurements, we used the electronic manometer to record the pressure drop between the various taps on pipe A, from 2 through 11.

The process was repeated for a reduced flow rate of 20 mm H_2O, and again after replacing the round elbow with the capped T-joint in both configurations, T1 and T2. This resulted in six datasets for head loss along the pipe for different flow rates and joint configurations.

Upon completion of the data collection, we powered down the system and restored the setup to its original state. The constants in our experiment included the static geometry of the pipe system, such as the length of the pipe over which the loss occurs, the pipe diameter, and the specific weight of the fluid. These constants were crucial for calculating the major and minor head losses using the provided equations and for estimating the friction factor f and the minor loss coefficient K_L for the airflow bench pipes, the round elbow, and the capped T-joints.

Barometric pressure (mm of Hg)	751.56
Ambient air temp (F)	69.9
Inclined manometer pressure (mm of H_2O) (Flow 1)	20
Inclined manometer pressure (mm of H_2O) (Flow 2)	40
Bench flow rate conversion factor (m3/s)(mm of H_2O)	2.5422E-4
Volumetric flow rate (m3/s) (Flow 1)	1.27E-05
Volumetric flow rate (m3/s) (Flow 2)	6.36E-06
Density of air (kg/m^3)	1.293

Table 1. Given values from lab

Key Equations:

In our lab, we delve into the study of pressure losses in pipe flow, which are influenced by the viscous stresses on the pipe walls. These losses are dependent on the flow's Reynolds number and the pipe wall's surface roughness. We describe these losses using the friction factor, denoted as f, which is a non-dimensional parameter representing pressure loss per unit length of the pipe. This factor is crucial in understanding the behavior of flow in pipes, whether it be laminar or turbulent.

We encounter two types of frictional losses in pipes: major losses and minor losses. Major losses occur due to friction in a long, unchanging stretch of pipe, while minor losses result from friction at pipe fittings such as junctions, bends, elbows, and valves. Our lab aims to quantify these losses under varying flow and pipe conditions.
The pressure change due to major losses is given by the Darcy-Weisbach equation, which is expressed as:

$$\Delta P = f \frac{l \rho v^2}{2D}$$

In this equation, we will refer to it as equation 1, l represents the length of the pipe over which the loss occurs, measured in meters; D is the pipe diameter in meters; ρ is the fluid density in kilograms per cubic meter; and v is the fluid velocity in meters per second. To convert this pressure change into head loss, we divide by the specific weight of the fluid, γ, yielding:

$$h_L^{major} = f \frac{l}{D} \frac{v^2}{2g}$$

where g is the acceleration due to gravity, 9.81 meters per second squared. We will refer to it as equation 2.

Minor losses, on the other hand, are associated with pipe fittings and are quantified by the head loss:

$$h_L^{min} = K_L \frac{v^2}{2g}$$

Here, K_L is the minor loss coefficient, which is determined empirically for each type of pipe fitting. We will refer to it as equation 3.

The theoretical framework for these equations assumes steady, incompressible flow and neglects elevation changes along the pipe. The friction factor f is a function of the flow regime, which is determined by the Reynolds number. For laminar flow, f depends solely on the Reynolds number, while for turbulent flow, it also depends on the pipe's relative roughness. The minor loss coefficient K_L is empirically determined and varies with the fitting type and configuration.

During our lab, we will use Equations 1, 2, and 3 to calculate the major and minor head losses in a pipe system. These calculations will involve measurements of pressure drops, flow rates, and the physical dimensions of the pipe system. By applying these key equations, we aim to understand the impact of flow and pipe conditions on frictional losses, which will enhance our knowledge of fluid dynamics in pipe systems.

Results:

Below are graphs showing the relationship between the pressure drop measurements in Pascals and the distance from the reference R1 in meters for each flow.

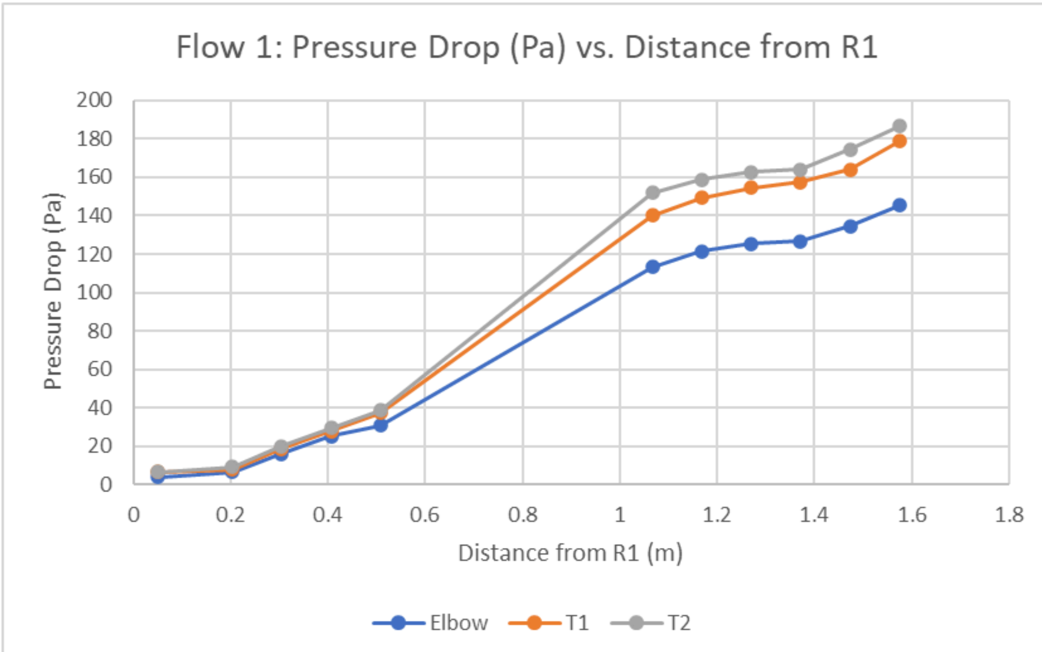

Figure 2: Pressure Drop vs Distance from R1 for Flow 1 (20mm H_2O)

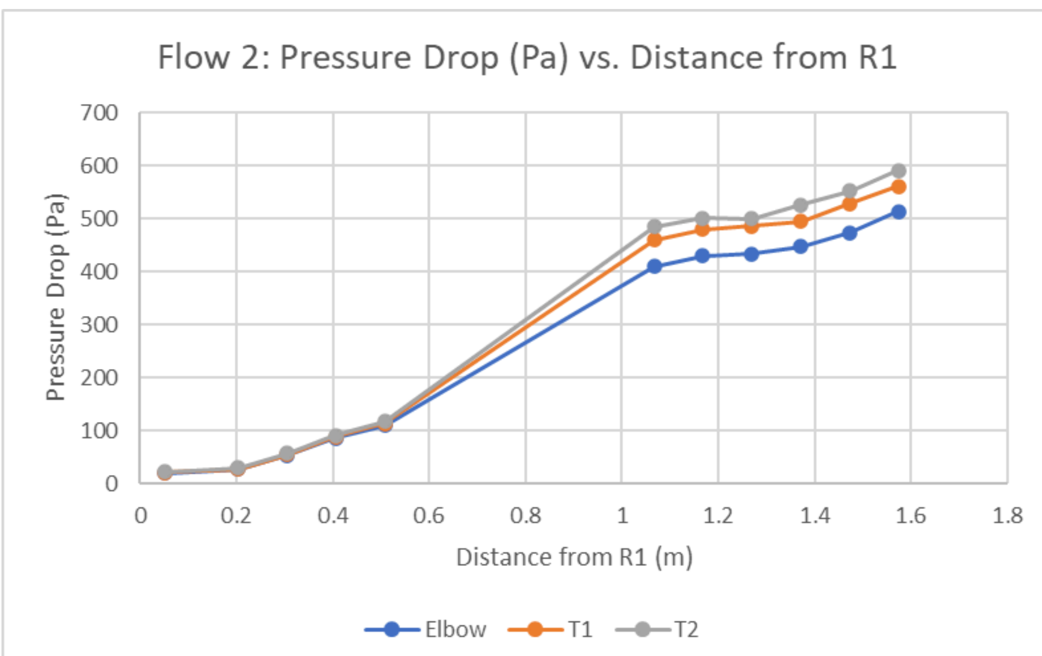

Figure 3: Pressure Drop vs Distance from R1 for Flow 2 (40mm H_2O)

We were able to estimate the friction factor f for major losses along the pipe by rearranging the equation for the pressure difference due to a major loss, $\Delta P = f\frac{l\rho v^2}{2D}$ to $f = \frac{2D\Delta P}{l\rho v^2}$.

We were also able to estimate the minor loss coefficient K_L by using the relationship $K_L = \frac{h_{L\,minor}}{(V^2/2g)} = \frac{2\Delta P}{\rho V^2}$.

Using these estimated values, we are able to calculate the total major head losses and minor head losses for the different setups using the equations $h_L^{major} = f\frac{l}{D}\frac{v^2}{2g}$ and $h_L^{min} = K_L\frac{v^2}{2g}$.

The values for the friction factors, minor loss coefficients, and major and minor head losses are tabulated below. Note: flow 1 = 20mm H_2O, and flow 2 = 40mm H_2O

Pipe and Flow	Friction factor	Minor loss coefficient	Major head losses (m)	Minor head losses (m)
Elbow, flow 1	0.0471	1.72	6.35	6.42
T1, flow 1	0.0592	2.11	7.81	7.89
T2, flow 1	0.0624	2.23	8.26	8.34
Elbow, flow 2	0.0433	1.52	22.58	22.80
T1, flow 2	0.0470	1.68	24.89	25.14
T2, flow 2	0.0493	1.76	26.08	26.34

Table 2: calculated friction factors, minor loss coefficients, and major and minor losses for different pipe fittings and flow rates

From the table, we can see how the different calculated values vary among the different flows, as well as the different pipe fittings. It is interesting that, from this data, we see that the friction factors and minor loss coefficients are greater for flow 1, while the major and minor head losses are greater for flow 2. For both flows, we can see a consistent change in every calculated value as the pipe fitting changes from the elbow to T1 to T2.

To calculate the Reynolds Number R_e, we can use the equation $R_e = \frac{\rho VD}{\mu}$, with $\mu = 1.825 \times 10^{-5}\ kg/ms$ for a temperature of ~20 degrees celsius.

For the first flow (20mm H_2O), a Reynold's number of 15352 was calculated.
For the second flow (40mm H_2O), a Reynold's number of 30762 was calculated.

These values are plotted on the Moody graph below with the two flows' corresponding calculated friction factors.

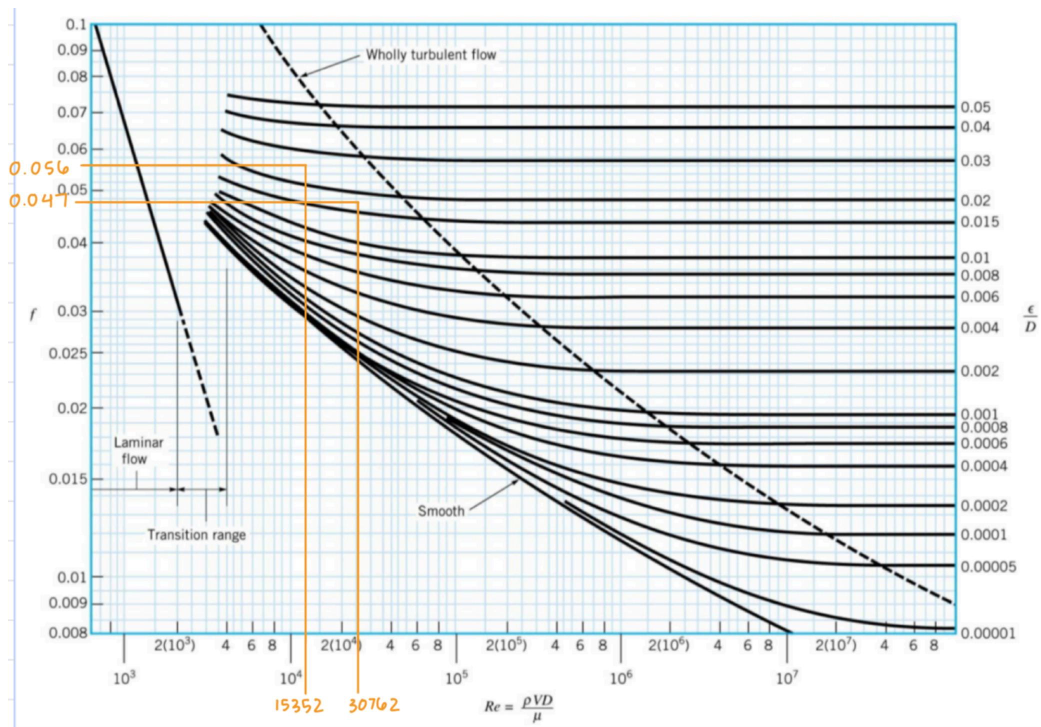

Figure 4: Calculated Reynold's number and friction factor plotted on Moody Graph

The results show that the flows through the pipe are turbulent. This can be seen from the Moody graph; the calculated Reynold's numbers and their corresponding friction factors meet up in the turbulent area of the graph.

Discussion:

Overall, the larger flow rate (40mm H_2O) through the T2 pipe configuration produced the greatest head losses, both minor and major. These are only slightly larger than those produced by T1, with ~4.6% difference. The values for the friction factor do not vary too much between the 20mm H_2O and the 40mm H_2O. Those for the 40mm H_2O are more consistent than those for the 20mm H_2O, varying only ~13% compared to ~30%. We should not expect any differences because the friction factor is directly proportional to pressure and inversely proportional to the velocity squared. Due to Bernoulli relationships between pressure and velocity, these proportionalities suggest that the friction factor be consistent for any flow. The difference in the friction factors can be attributed to the many possible sources of error that will be described, mainly due to the variety of assumptions that our calculation equation uses.

Based on the setup of our apparatus and nature of our experiment, minor losses likely caused greater head losses in the system than any major losses, regardless of flow and pipe fitting. This is what we expected for this lab. The minor losses are mainly attributed to the pipe fittings that were attached in the set up, while the major losses were primarily due to friction. The flow had to move through different bent shapes, which resulted in head loss. The T2 pipe juncture caused the greatest head loss for both flows. Based on where the measurements fell on the Moody Diagram, we can see that the system consisted of relatively smooth pipes. The roughness factors from the diagram are ~0.02 and ~0.03, which correspond to some material similar to welded or galvanized steel, which is what we observed the pipes to be a similar material to. This relative roughness factor isn't low enough for us to be in the 'smooth' section of Moody's diagram, but it also isn't rough enough for us to assume a large amount of losses due to friction.

There were a few potential errors in our data acquisition that may have affected our results. For one, the reading of the pressure values was not very precise. The values displayed on the bench fluctuated and typically did not reach an equilibrium with a reasonable amount of time, so we took an 'average' reading based on the range of values that was observed for a certain 'tap'. These observed values may not have been the accurate pressure reading, which would produce pressure values that were either too high or too low, affecting our calculated values since they all depended on the measured pressure. The flow rate values were also not obtained in a very precise way, as they were estimated from a slanted tube of liquid. The calculated velocity depends on this flow rate, so an estimated value is unlikely to give us a precise fluid velocity.

Another source of possible error is that we had a relatively high Reynolds number, meaning the flow is turbulent. The eddies that likely formed in this flow can create a pretty non-uniform velocity profile, which would change the amount of pressure we were able to read from the apparatus due to the varying streamlines and dynamic pressure. We are also operating under the assumption that these pipes have been uniformly produced, with no variation in their diameter or roughness. Imperfections in these pipes and within the bends we were measuring would change our results due to additional losses. The equations used in our calculations also do not account for changes in elevation along our pipe, which we have seen to be a factor in our measurements in the lab building. The floor is at a slight angle, which could possibly affect the velocities we calculated from our flow.

Conclusions:

In conclusion, our investigation examined the effects of flow rates and pipe configurations on pressure losses in pipe systems. We explored the relationships between the Reynolds number, friction factor, surface roughness, and their contributions to major and minor pressure losses as described by the Darcy-Weisbach equation and minor loss coefficients. We observed that both the major and minor losses scaled with flow rate. Minor losses were especially significant at higher flow rates due to the presence of fittings like elbows and T-joints. These observations supported our hypothesis that increased flow rates would lead to higher pressure losses due to enhanced frictional forces and flow disruptions– particularly in turbulent flow and at pipe fittings.

The measured friction factors did not vary by much between the 20mm H2O and the 40mm H2O, which should be expected because the friction factor is directly proportional to pressure and inversely proportional to the velocity squared. The Bernoulli relationships between pressure and velocity suggest that the friction factor be consistent for any flow, so any differences can be accounted for through our errors and assumptions. Potential sources of error in our data acquisition process include imprecise pressure and flow rate readings, assumptions about pipe uniformity, and neglecting elevation changes along the pipe. These factors impacted our analysis and calculated results.

Our investigation provided valuable insights into the dynamics of pressure losses in pipe systems, emphasizing the importance of accounting for factors such as flow rates, surface roughness, and pipe configurations when analyzing fluid flow behavior. Further research incorporating more precise measurement techniques and accounting for additional variables could enhance our understanding of these phenomena and their practical implications in engineering applications.

Appendix:

A. Lab Data Sheet

	volumetric flow rate (mm H2O)	20			40			
	volumetric flow rate (m^3/s)	5.08E-03			1.02E-02			
Pipe location	Distance from R1 (delta L) (in)	Elbow	T1	T2	Elbow	T1	T2	
1	61	1.29	1.49	1.48	5.59	6.65	6.14	
2	57	1.24	1.44	1.43	5.41	6.5	5.94	
3	53.125	1.19	1.39	1.38	5.26	6.39	5.79	
4	49.25	1.14	1.33	1.31	5.08	6.15	5.63	
5	45.25	1.08	1.29	1.26	4.95	6.06	5.48	
6	41.25	1.03	1.24	1.2	4.78	5.85	5.39	
7	19.75	0.44	0.39	0.46	2.49	2.62	2.49	
8	15.75	0.38	0.35	0.4	2.33	2.46	2.33	
9	11.875	0.34	0.3	0.36	2.17	2.27	2.17	
10	8	0.3	0.26	0.32	2.05	2.14	2.04	
11	4	0.25	0.21	0.27	1.88	1.95	1.88	
R1	0	0	0	0	0	0	0	
inside pipe diameter (in)	1.11							
inside T diameter (in)	1.13							
Inside elbow diameter (in)	1.18							
Air Temp (F)	69.9							
Barometric Pressure (mm Hg)	751.56							
Bench flowrate constant (mm H2O)	2.54E-04							