ENGG *2230

Fluid Mechanics: Lab 1

Laboratory #1 – Friction Loss in a Pipe

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Section #3 - Group A1

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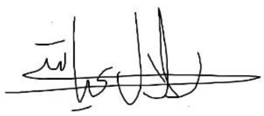

GTA: Christopher Sullivan

Introduction

The purpose of this experiment is to investigate the change in frictional resistance in laminar and turbulent regions, by examining the head loss of the fluid as it traverses along the pipe in high flow and low flow situations. Fluids undergo frictional resistance from the pipe as they travel and this rate of loss, "*i*", is referred to as the hydraulic gradient (Joy 2018). There are two types of flows; laminar flow occurring at low velocities, and turbulent flow occurring at high velocities (Joy 2018). Reynolds number (Re) is a dimensionless value that is determined by density velocity, pipe dimensions and fluid viscosity, and can be used to determine if a fluid is laminar or turbulent depending on a critical value (Joy 2018). The critical Re for this experiment is theoretically 2000 (Joy 2018). Below this value laminar flow exists and above this value turbulent flow exists. Calculations of hydraulic gradient in the laminar region can be used to determine the coefficient of viscosity (μ) from equation 17 (Joy 2018). Measurements in the turbulent region can be used to find the friction factor (f) from equation 18 in the lab manual (Joy 2018).

A common example of friction loss in a pipe is in home plumbing systems, especially in sinks and bathrooms. Another possible example is loss of pressure in water towers, the immense vertical distance of pipes along the tower can cause friction as the fluid moves along, resulting in decreased pressure. This can negatively impact the performance of the water tower. Therefore, it is very important to understand how resistance of fluid affects movement.

Description of Apparatus

Water from the supply tank is transferred through a hose to a manometer junction. A Piezometer reads the pressure of the water entering the system at a given flow rate for high flow systems. The readings depict the differential pressure directly in mm of water. Low flow systems are measured by manometers that are connected to a U-tube which measures the pressure differential between the two junctions. Due to the relatively slow flows, the discharge is measured using a graduated cylinder and a stop watch.

Experimental Procedure

The experiment is conducted to examine both types of flow, using a procedure for high flow and a separate procedure for low flow. For each procedure, two trials will be performed at eight decreasing increments.

To begin the experiment with high flow, the needle valve, main supply valve and manometer closed, the pump is turned on (Joy 2018). The bench valves are then opened. Trapped air in the lines is removed by pressing the needle into the high flow needle valves. The U-tube may be pressurized to have readings near the middle for ease of readings. Open the bleed valves to a max setting (Joy 2018). Change the flow output and record the gauge reading and use a graduated cylinder to measure the discharge of water. This is done by letting it fill up to a known level, and recording the time using a stop watch. Measure the discharge twice to mitigate errors (Joy 2018). Adjust the needle valve to start a new trial. Repeat this procedure 7 more times.

The low flow experiment starts the same but the tapping is switched to the low flow setting. The hose from the pump is connected to a low flow head tank (Joy 2018). The head tank is essentially a storage tank with a vertical pipe in the centre which allows excess water to drain into the pipe. The manometer is opened and the supply valve is opened slowly. As the head tank fills slowly, it is carefully observed so that it does not overflow, and that the level is at a point of steady state. The needle valve is opened slightly to remove any air bubbles from the pipe (Joy 2018). Close the needle valves and make the manometer levels equal by using a hand pump. Open the needle valve fully and measure the discharge for approximately sixty seconds. Read the bottom of the meniscus in the middle of the fluctuation in the two manometer tubes. Reduce the discharge by tightening the needle valve for 8 increments total.

Results

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High Flow:

Trial No.	Volume [mL] Rep 1	Volume [mL] Rep 2	Time [s] Rep 1	Time [s] Rep 2	Gauge Reading (Y) [mm]
1	1000	1000	38.91	38.40	3800
2	1000	950	39.65	39.00	3600
3	1000	1000	40.28	41.29	3400
4	1000	~~950~~	44.25	~~47.43~~	3200
5	1000	1000	47.34	47.03	2800
6	1000	1000	52.44	52.69	2400
7	1000	1000	55.69	55.53	2200
8	1000	1000	59.57	60.34	2000

→ 1000 + 44.09

Low Flow:

Trial No.	Volume [mL] Rep 1	Volume [mL] Rep 2	Time [s] Rep 1	Time [s] Rep 2	Manometric levels [mm] A	Manometric levels [mm] B
1	480	460	~~[illegible]~~ 62.31	60.68	528	108
2	440	430	61.94	60.60	510	134
3	390	395	60.44	61.28	482	171
4	360	345	62.38	57.69	460	210
5	320	320	60.78	59.63	~~[illegible]~~ 438	234
6	297	270	61.00	57.97	418	260
7	220	221	57.69	57.94	400	287
8	170	165	59.50	57.91	~~360~~ 376	~~329~~ 318

Diameter of tubing: 3.0mm
Length of tubing: 524 mm

4. PRESENTATION OF RESULTS

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The raw data collected for the low and high flow trials was used to calculate the discharge, velocity, hydraulic gradient and Reynolds number for each flow. The calculated values can be seen in table 1 and table 2. A collection of sample calculations follows the tables. Theoretical values used in the calculations in this experiment are listed below.

$$D = 0.003\ m$$

$$\rho = 998\ kg/m^3$$

$$\mu = 0.001002\ kg/m \cdot s$$ ("Viscosity", 2018)

$$g = 9.81\ m/s^2$$

Table 1 – Low Flow Calculated Values

Trial No.	Area $[m^2]$ $(x\ 10^{-6})$	Discharge (Q) $[m^3/s]$ $(x\ 10^{-6})$	Velocity (u) [m/s]	Hydraulic Gradient (i)	Reynolds Number (Re)
1	7.069	7.642	1.081	0.802	3230
2	7.069	7.100	1.004	0.718	3001
3	7.069	6.449	0.912	0.594	2726
4	7.069	5.876	0.831	0.477	2484
5	7.069	5.316	0.752	0.389	2247
6	7.069	4.763	0.674	0.302	2014
7	7.069	3.814	0.540	0.216	1612
8	7.069	2.853	0.404	0.111	1206

Table 2 – High Flow Calculated Values

Trial No.	Area $[m^2]$ $(x\ 10^{-6})$	Discharge (Q) $[m^3/s]$ $(x\ 10^{-6})$	Velocity (u) [m/s]	Hydraulic Gradient (i)	Reynolds Number (Re)
1	7.069	2.587	3.660	7.252	10936
2	7.069	2.479	3.507	6.870	10479
3	7.069	2.452	3.469	6.489	10366
4	7.069	2.264	3.203	6.107	9570
5	7.069	2.119	2.998	5.344	8959
6	7.069	1.902	2.691	4.580	8042
7	7.069	1.798	2.544	4.198	7602
8	7.069	1.668	2.360	3.817	7051

Sample Calculations

Area

$$A = \pi r^2$$

$$A = \pi \left(\frac{0.003\ m}{2}\right)^2$$

$$A = 7.069\ x\ 10^{-6}\ m^2$$

Discharge (Q)

$$Q = \frac{V}{t}$$

$$Q = \frac{1000\ mL\ (\frac{10^{-6} mL}{1\ m^3})}{38.91\ s}$$

$$Q = 2.570\ x\ 10^{-5}\ m^3/s$$

$$*\ Final\ Q\ value\ is\ average\ of\ calculated\ Qs\ for\ both\ repetitions$$

Velocity (u)

$$u = \frac{Q}{A}$$

$$u = \frac{2.587\ x\ 10^{-5}\ m^3/s}{7.069\ x\ 10^{-6}\ m^2}$$

$$u = 3.660\ m/s$$

Hydraulic Gradient (i)

$$i = \frac{dh}{dL}$$

(a) High Flow

$$i_{High\ Flow} = \frac{3.800\ m}{0.524\ m}$$

$$i_{High\ Flow} = 7.252$$

(b) Low Flow

$$i_{Low\ Flow} = \frac{(0.528\ m - 0.108\ m)}{0.524\ m}$$

$$i_{Low\ Flow} = 0.802$$

Reynolds Number

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

$$Re = \frac{998\ kg/m^3 (3.660\ m/s)(0.003\ m)}{0.001002\ kg/m \cdot s}$$

$$Re = 10936$$

The log of the hydraulic gradient was plotted, dependent on the log of velocity, in figure 1. The trends displayed in this graph can be used to determine the turbulence of the flows.

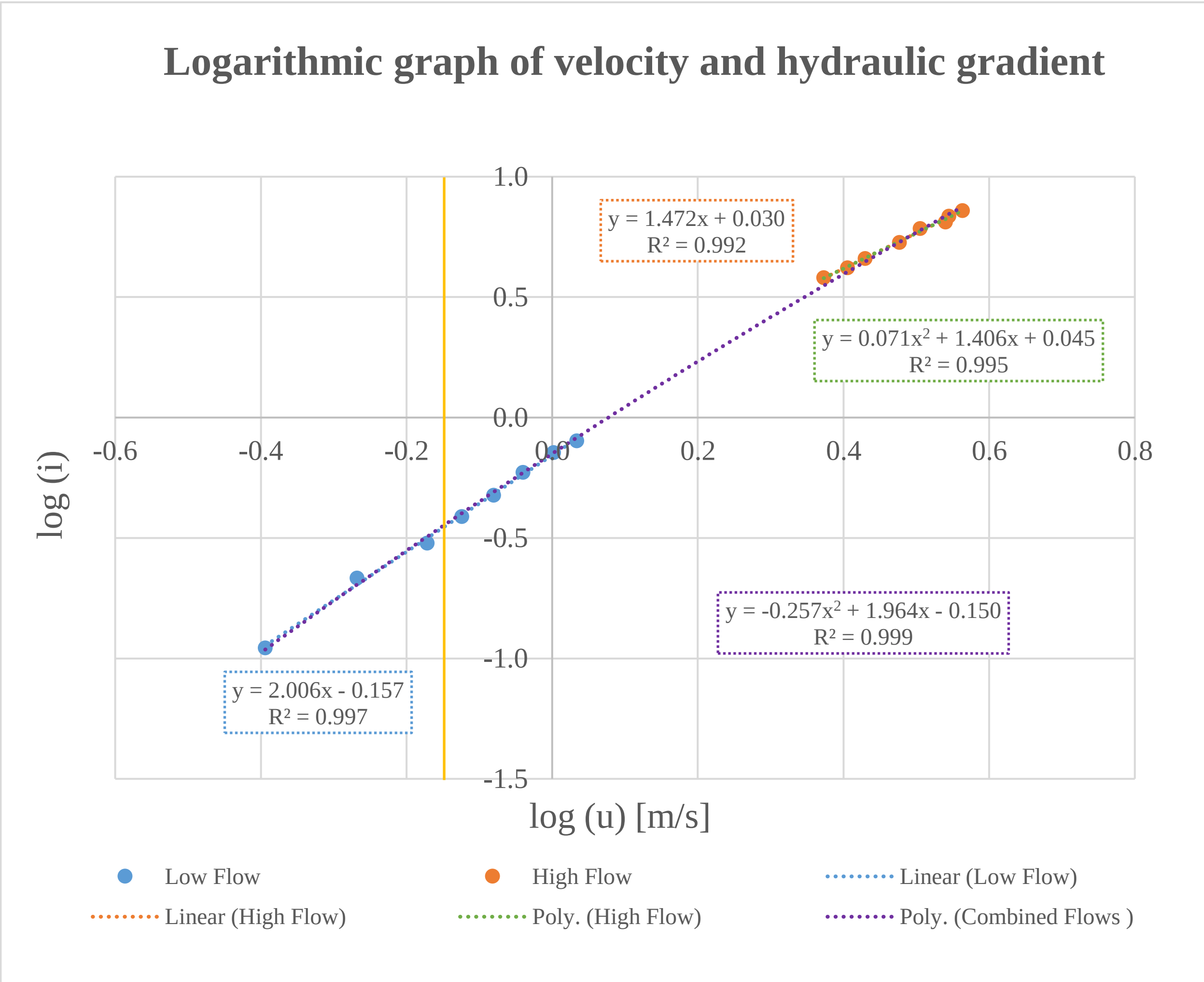

Figure 1 – Logarithmic graph of velocity and hydraulic gradient

Laminar and turbulent flow have different relationships between hydraulic gradient and velocity of flow (Joy, 2018). For laminar flows, hydraulic gradient is linearly dependent on velocity (Joy, 2018). Turbulent flows have the relation,

$$i \propto u^n$$

where n is an index dependent on the Reynold's number and characteristics of the pipe wall that is between 1.7 and 2.0 (Joy, 2018). The three trend lines set to one of the 2 data sets in figure 1 display this relationship. The low flow trials can be fit with a linear trend line with an R^2 value of 0.997 which is very close to 1. This suggests the low flow region displays laminar flow and has an n value of 1. The high flow region was fitted with a linear and a quadratic trend line. Both trend lines have R^2 values very close to 1, however the quadratic trend line is slightly closer with 0.995 as compared to 0.992. Therefore, this suggests the n value lies between 1 and 2 and is slightly closer to 2. This agrees with the theoretical n values for turbulent flow, therefore it is likely the high flow experiences turbulent flow.

A trend line was set to both the low flow and high flow data sets. The best fit was a quadratic trend line with a R^2 value of 0.999. The point at which the flow changes from laminar to turbulent flow was chosen to be the place in the low flow region where the linear trend line diverges from the overall quadratic trend line. This point occurs at a log(u) value of -0.15 which corresponds with a velocity of 0.708 m/s.

The critical Reynold's number is calculated using this transition velocity.

$$Re_{critical} = \frac{\rho u D}{\mu}$$

$$Re_{critical} = \frac{998\ kg/m^3(0.708\ m/s)(0.003\ m)}{0.001002\ kg/m \cdot s}$$

$$Re_{critical} = 2115$$

The critical Reynold's number presented in the lab manual is 2000 (Joy, 2018). The percent error between these two values is;

$$\%\ error = \frac{|Re_{theoretical} - Re_{experimental}|}{Re_{theoretical}}(100\%)$$

$$\%\ error = \frac{|2000 - 2115|}{2000}(100\%)$$

$$\%\ error = 5.75\ \%$$

The percent error between the experimental and theoretical Reynold's number is fairly small therefore suggesting that the transition velocity found above accurately represents the transition between laminar and turbulent regions.

Rearranging equation 17, the viscosity of the fluid can be determined using the laminar region (Joy, 2018). The trials with velocities less than the transition velocity were used to calculate viscosity. This includes trials 6, 7 and 8 from the low flow trials.

$$\mu = \frac{igD^2\rho}{32u}$$

$$\mu = \frac{0.111(9.81\ m/s^2)(0.003\ m)^2(998\ kg/m^3)}{32(0.404\ m/s)}$$

$$\mu = 0.00076\ kg/m \cdot s$$

$$*\ take\ average\ of\ viscosity\ caluclated\ from\ the\ 8\ low\ flow\ trials$$

$$\mu_{avg} = 0.00103\ kg/m \cdot s$$

The percent error of the experimental viscosity was calculated below.

$$\%\ error = \frac{\left|\mu_{theoretical} - \mu_{experimental}\right|}{\mu_{theoretical}}(100\%)$$

$$\%\ error = \frac{|0.001002\ kg/m \cdot s\ \ - 0.00103\ kg/m \cdot s|}{0.001002\ kg/m \cdot s}(100\%)$$

$$\%\ error = 2.79\ \%$$

Rearranging equation 18, the friction factor can be calculated using the turbulent region. This region is taken to be the velocities after the transition velocity and therefore include all of the high flow trials as well as trials 1-5 of the low flow trials.

$$f = \frac{iD2g}{u^2}$$

$$f = \frac{7.252(0.003\ m)(2)(9.81\ m/s^2)}{(3.660\ m/s)^2}$$

$$f = 0.0319$$

$$*\ take\ average\ of\ friction\ factors\ calculated\ from\ the\ 8\ high\ flow\ trials$$

$$f_{avg} = 0.0382$$

Using the viscosity determined in this experiment and the transition velocity, the critical Reynold's number is;

$$Re_{critical} = \frac{\rho u D}{\mu}$$

$$Re_{critical} = \frac{998\ kg/m^3 (0.708\ m/s)(0.003\ m)}{0.00103\ kg/m \cdot s}$$

$$Re_{critical} = 2058$$

The percent error between the Reynold's number calculated with the theoretical viscosity and the percent error calculated with the experimental viscosity is;

$$\%\ error = \frac{|Re_{theoretical} - Re_{experimental}|}{Re_{theoretical}}(100\%)$$

$$\%\ error = \frac{|2115 - 2058|}{2115}(100\%)$$

$$\%\ error = 2.70\ \%$$

Discussion

During this experiment, our result was affected by both systematic errors and random errors. The precision of the gauge readings and manometric levels was fairly low which decreases the accuracy of the results. The occurrence of air bubbles in the system during the experiment may have led to inaccurate readings that could have affected the final results. Another error may be from the observer. The stop watch was dependent on human reaction time, which can increase the time measured therefore decreasing the discharge value. The method of calculating discharge depended on filling a graduated cylinder which is less accurate than the more time consuming method using the weigh tank. The accuracy of readings of the lower meniscus on the manometer could be lowered due to the fluctuations of the fluid.

The calculated theoretical viscosity was 0.001002 kg/m·s and the experimental viscosity was calculated to be 0.00103 kg/m·s using the laminar region. The percent error of the experimental viscosity was calculated to be 2.79% which is fairly low, therefore suggesting the above mentioned errors had minimal effect on the results. The percent error of the critical Reynold's number was calculated to be 5.75% with a theoretical value of 2000 and an experimental value of 2115. The difference between the experimental and theoretical

Reynold’s number is small, therefore suggesting that the transition velocity found above on tables 1 and 2 accurately represents the transition between laminar and turbulent regions. The percent error between the critical Reynold’s numbers calculated with the theoretical and experimental viscosity is quite low at 2.70% suggesting that small variations between the viscosities does not have a large impact in the Reynold’s calculations.

Conclusion

As the velocity of a flow increases, the flow model evolves from laminar to turbulent. It was evident from figure 1 that increased velocity of the fluid lead to higher values of hydraulic gradient. The hydraulic gradient is linearly proportional to velocity of fluid for laminar flow and is proportional to power between 1 and 2 for turbulent flow. Using the trends of the flow regions, a transition velocity between the laminar and turbulent regions was found to be 0.708 m/s. Using literature values for viscosity, the experimental Re was found to be 2115 which has an experimental error of 5.75% when compared to the theoretical value of 2000. Rearranging equation 17 and 18 from the lab manual allowed for the determination of viscosity and friction factor. The experimental viscosity had a very low percentage error compared to a literature value and was found to be 0.00103 kg/m·s. The critical Reynold’s number was then calculated using the experimental viscosity and was found to be 2058. The friction factor was determined from the turbulent regions to be 0.0382. This experiment shows that the critical Reynold’s number is often very small and for laminar flow to exist, the fluid must be heavily controlled, especially to mitigate the effects or friction in pipes.

Works Cited

Joy, D. M. (2018). Fluid mechanics laboratory manual. Guelph, ON: University of Guelph, School of Engineering.

Viscosity. (2018). *Saylor.org*. Retrieved February 25 2018, from https://www.saylor.org/site/wp-content/uploads/2011/04/Viscosity.pdf