Lab#5: Energy Losses in Pipes

CE 336

Department of CECEM

Group Report

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September 20, 2022
Fall 2022

Purpose of Study

The purpose of this experiment is to demonstrate the concept of major losses when fluids flow through pipes. The experiment will show how different pipes that vary in size and roughness can affect energy loss in pipes. Smooth and rough pipes will be used to understand how the texture can affect frictional loss in pipes.

Introduction

Throughout this experiment were plentiful observations of a fluid, in this case water, flowing through differing smoothness and diameters or piping at incremental flow rates. Theoretically, the fluid was uniform throughout the experiment and the all of the equipment for measuring remained the same as well as the temperature, so the main contributing factors that were dictating the major losses through pipes would be the cross-sectional area of the pipes, smoothness of the pipes, and the flow rate at each given measurement interval. In practicality, the roughness of the pipe is calculated through numerical analysis to estimate the roughness factor (ε/D). Also all of the collected results for volume, time elapsed, and measured head loss is used to determine flow rate (Q), flow velocity (V), the respective Reynold's numbers (Re), friction factor (f), friction loss, and category of flow.

Theory

Osborne Reynolds showed two types of flow that can form in a pipe; Laminar and Turbulent flow. He created a unit less number known as Reynolds Number (Re). Reynolds Number is defined as:

$$\mathrm{Re} = \frac{VD}{v} = \frac{\rho VD}{\mu} \quad (1)$$

V is the flow velocity through the pipe, D is the diameter of the pipe, v is the kinematic viscosity of the fluid, μ is the dynamic viscosity of the fluid, and ρ if the density of the fluid. Re < 3000, flow is laminar. Re > 5000 is turbulent. For Re 3000<Re<5000 flow is transitional and flow characteristics are not accurately defined.

Henry Dacry and Julius Weisbach formed a relationship to measure the head loss in pipes. The Darcy-Weisbach frictional head loss equation is defined as:

$$h = f\,\frac{L}{D}\,\frac{V^2}{2g} \quad (2)$$

Where g is gravity constant and f if the Darcy-Weisbach friction factor. For a flow that is laminar, the friction factor varies linearly with Reynolds Number as follows:

$$f = \frac{64}{Re} \quad (3)$$

For a flow that is turbulent, friction factor is dependent on Re and the relative roughness of the pipe material (ϵ/D). Lewis Moody created a graph that can be used to find friction factor f for laminar and turbulent flow. This chart is known as the Moody Chart.

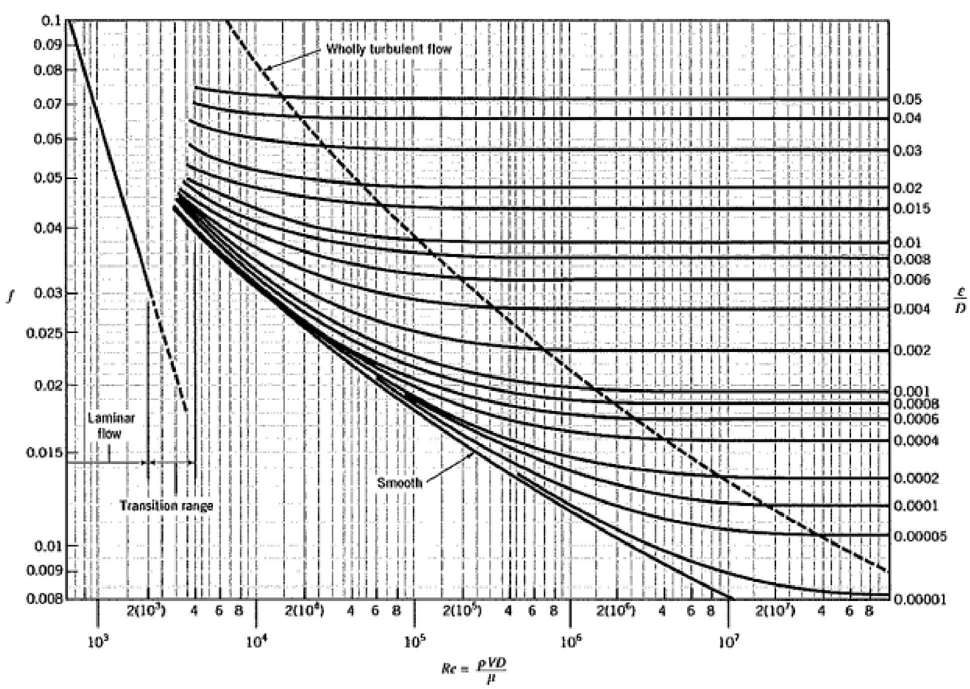


Figure 1. Moody Chart

The chart shows four zones of flow in a pipe:

1. Flow that is laminar where the friction factor is linearly decreasing with an increase in Reynolds Number
2. Transitional zone where characteristics of the flow cannot be defined as turbulent or laminar
3. Transitional turbulent zone where friction factor depends on Re and the relative roughness of the pipe material
4. Turbulent zone where friction factor is independent of Re and varies only with the relative roughness of the pipe material

Friction factor can also be calculated using the Swamee-Jain equation as follows:

$$f = \frac{0.25}{\left[log\left(\frac{\frac{e}{D}}{3.7} + \frac{5.74}{Re^{0.9}}\right)\right]^{2}} \quad (4)$$

Equipment

The equipment utilized for this experiment were 4 smooth pipes with varying diameter, along with one rough pipe with diameter equal to the 4th pipe. Probes were also used as attachments to the pipes in order to determine head losses, along with a water nanometer to find pressure drop. A hydraulic bench was also used.

Figure 2. C6-MKII-10 Armfield apparatus

Figure 3. Roughened Pipe

Experimental Set-Up and Procedures

The experiment has two exercises.

Exercise 1: Flow through smooth pipes

First, the valve of the hydraulic bench was shut off completely, and the hydraulic bench pump was turned. Next, the valve of the 5mm diameter pipe was opened to establish flow through the pipe. Then the valve in the hydraulic bench was slowly opened to have a very low flow. We used the cylinder and stopwatch to record the time it takes to fill the cylinder to a certain volume, which is our first flow rate data. In order to find the pressure drop or head loss through the pipe when flow is low, we used a water manometer. We connected the water manometer with the two tapings in the pipe using tubing and connectors. And then recorded the pressure drop in the pipe. Next, we increased the flow rate in the hydraulic bench and recorded the flow rate by recording the time required to collect a certain volume of water as done previously. Again, we used a cylinder to collect the volume of water for low flows, and recorded the pressure drop for this new flow rate. These steps were then repeated to collect a total of 10 readings for different flow rates starting with very low flow to high flow. For high flow, we used a pressure measurement device to record pressure drop in the pipe by connecting the two tapings in the pipe using tubing and connectors, and recorded the pressure drop in the pipe.

We then closed the valve of the 5mm diameter pipe, and opened the 8mm diameter pipe. We took 10 readings of different flow rate through the pipe and corresponding pressure drop using cylinder, stopwatch and pressure meter. We repeated the same procedure for the 11mm and 17mm diameter pipe and took 10 readings of flow rate and pressure drop for each pipe. Finally, using a Vernier scale, we recorded the internal diameter of the test pipe samples.

Exercise 2: Flow through roughened pipe

We repeated the same procedure for the roughened pipe for 10 readings of different flow rates by altering the flow using the control valve on the hydraulic bench. We used a water manometer to measure pressure drop in the pipe. Using the Vernier scale, we estimated the nominal internal diameter of the test pipe sample and the roughness factor.

Discussion

Table 1. Smooth Pipe D=5mm

Area = 2×10^{-5} m^2

Volume V (L)	Time t (s)	Flow Rate Q (m^3/s)	Velocity (m/s)	Reynold's Number Re	Calculated Friction Factor f	Calculated Head Loss hc (m H_2O)	Measured Head Loss hm (mH_2O)
0.06	10.08	0.000005952380952	0.3031522726	1353.35836	0.0472897659	0.04430164097	0.033
0.113	10.06	0.00001123260437	0.5720718432	2553.892157	0.02505978956	0.08360063143	0.164
0.135	10.1	0.00001336633663	0.6807419348	3039.026495	0.02105937547	0.09948130864	0.226
0.155	10.18	0.0000152259332	0.7754504103	3461.832189	0.01848732015	0.1133216828	0.288
0.185	10.11	0.00001829871414	0.9319458587	4160.472583	0.01538286786	0.1361913948	0.394
0.205	10.09	0.00002031714569	1.034743733	4619.391666	0.01385463815	0.1512139262	0.493
0.24	10.09	0.00002378592666	1.211407297	5408.068291	0.01183417009	0.177030938	0.606
0.25	10.04	0.00002490039841	1.268166877	5661.459273	0.01130450594	0.1853255897	0.705
0.248	9.93	0.00002497482377	1.27195733	5678.380936	0.01127081834	0.1858795135	0.748
0.225	9.99	0.0000225	1.1470626	5120.8154	0.0124980	0.1676278	0.566

		2252252	53	15	0956	307	

Table 2. Smooth Pipe D=8mm

Area = 5×10^{-5} m^2

Volume V (L)	Time t (s)	Flow Rate Q (m^3/s)	Velocity (m/s)	Reynold's Number Re	Calculated Friction Factor f	Calculated Head Loss hc (m H_2O)	Measured Head Loss hm (mH_2O)
0.085	9.9	0.000008585858586	0.1708102293	1220.073067	0.05245587478	0.009750634906	0.011
0.09	9.97	0.000009027081244	0.1795880752	1282.771966	0.04989195407	0.01025171479	0.008
0.24	10.08	0.00002380952381	0.4736754259	3383.395899	0.01891590636	0.02703957579	0.06
0.37	9.93	0.00003726082578	0.7412805758	5294.861256	0.01208719113	0.04231571075	0.16
0.495	10.11	0.00004896142433	0.9740565879	6957.547057	0.009198644218	0.05560363805	0.315
0.365	4.91	0.00007433808554	1.478909222	10563.6373	0.006058519258	0.08442295251	0.555
0.41	4.97	0.00008249496982	1.641185278	11722.75199	0.005459468908	0.09368641752	0.759
0.38	4.17	0.00009112709832	1.812916018	12949.40013	0.004942313879	0.1034895994	0.895
0.4	4.22	0.00009478672986	1.885722075	13469.44339	0.004751495526	0.1076457046	0.994
0.35	3.57	0.00009803921569	1.950428224	13931.63017	0.004593862973	0.1113394297	0.923

Table 2. Smooth Pipe D=11mm

Area = 9.5×10^{-5} m^2

Volume V (L)	Time t (s)	Flow Rate Q (m^3/s)	Velocity (m/s)	Reynold's Number Re	Calculated Friction Factor f	Calculated Head Loss hc (m H_2O)	Measured Head Loss hm (mH_2O)
0.06	44.13	0.000001359619307	0.01430678568	140.5130736	0.4554736321	0.0004319720968	0.001
0.06	19.9	0.000003015075377	0.03172655537	311.6000974	0.2053914634	0.0009579361122	0.002
0.095	9.97	0.000009528585757	0.1002658859	984.7542363	0.06499083491	0.003027379171	0.003
0.13	10.01	0.00001298701299	0.1366576736	1342.17358	0.04768384728	0.004126175029	0.01
0.145	10.01	0.00001448551449	0.1524258667	1497.039762	0.04275103549	0.004602272148	0.011
0.2	9.97	0.00002006018054	0.2110860755	2073.166813	0.03087064658	0.006373429834	0.017
0.23	10.03	0.00002293120638	0.2412968494	2369.879771	0.0270055894	0.007285599179	0.011
0.295	10.19	0.00002894995093	0.3046299367	2991.901164	0.02139108095	0.009197847476	0.017
0.34	10.13	0.00003356367226	0.3531784693	3468.717109	0.0184506254	0.01066369815	0.021
0.38	9.89	0.00003842264914	0.404307738	3970.87957	0.01611733594	0.01220747031	0.023

Table 4. Smooth Pipe D=17mm

Area = $22.7 \times 10^{-5}\ m^2$

Volume V (L)	Time t (s)	Flow Rate Q (m^3/s)	Velocity (m/s)	Reynold's Number Re	Calculated Friction Factor f	Calculated Head Loss hc (m H_2O)	Measured Head Loss hm (mH_2O)
0.195	10.05	0.0000194	0.0854832	1297.5130	0.0493251	0.0010806	0.001

		0298507	1067	19	3128	42332	
0.195	9.97	0.00001955867603	0.08616913412	1307.924357	0.04893249342	0.001089313485	0.001
0.2	10.14	0.00001972386588	0.08689690661	1318.970904	0.04852267765	0.001098513674	0.001
0.28	10.22	0.00002739726027	0.1207033744	1832.10479	0.03493249969	0.001525880638	0.001
0.35	9.88	0.00003542510121	0.1560714178	2368.941163	0.02701628939	0.001972988376	0.001
0.41	10.05	0.0000407960199	0.1797339301	2728.104296	0.02345951366	0.002272119776	0
0.4	9.9	0.0000404040404	0.1780069966	2701.891912	0.02368710595	0.002250288618	0
0.405	10	0.0000405	0.1784297632	2708.308906	0.02363098237	0.002255633053	0.001
0.365	9.99	0.00003653653654	0.1609680386	2443.264871	0.02619445839	0.002034889369	0.001
0.39	7.47	0.00005220883534	0.2300150648	3491.300091	0.01833128013	0.002907752461	0.002

Table 5. Roughened Pipe D=17mm

Area = 22.7×10^{-5} m^2

Volume V (L)	Time t (s)	Flow Rate Q (m^3/s)	Velocity (m/s)	Reynold's Number Re	Calculated Friction Factor f	Calculated Head Loss hc (m H_2O)	Measured Head Loss hm (mH_2O)
0.37	9.97	0.000037111334	0.1635004083	2481.702627	0.02578874653	-0.05443390564	0.042
0.32	7.88	0.00004060913706	0.1789105854	2715.6071	0.0235674741	-0.05361198184	0.038
0.375	9.96	0.00003765060241	0.1658762487	2517.764489	0.02541937512	-0.05430056804	0.031

0.395	10.01	0.0000394 6053946	0.1738502 398	2638.7982 82	0.0242534 6432	-0.053871 09776	0.049
0.27	7.2	0.0000375	0.1652127 437	2507.6934 31	0.0255214 6096	-0.054337 54671	0.042
0.375	8.76	0.0000428 0821918	0.1885990 225	2862.6637 34	0.0223567 998	-0.053142 15964	0.041
0.37	7.22	0.0000512 465374	0.2257754 946	3426.9494 72	0.0186755 015	-0.051599 47988	0.038
0.41	6.54	0.0000626 911315	0.2761966 357	4192.2703 64	0.0152661 9098	-0.049974 16411	0.036
0.435	5.84	0.0000744 8630137	0.3281622 991	4981.0348 97	0.0128487 3552	-0.048663 20741	0.035
0.425	5.51	0.0000771 3248639	0.3398205 254	5157.9901 18	0.0124079 3381	-0.048406 0739	0.034

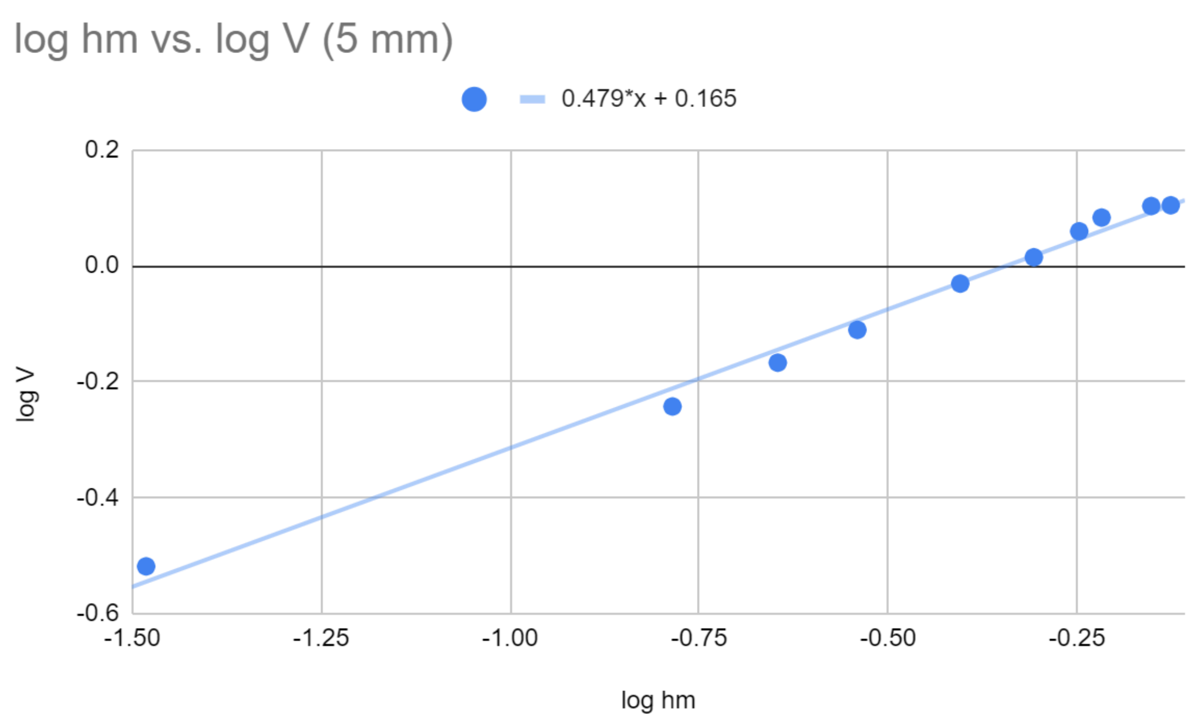


Figure 4. Smooth 5mm Pipe

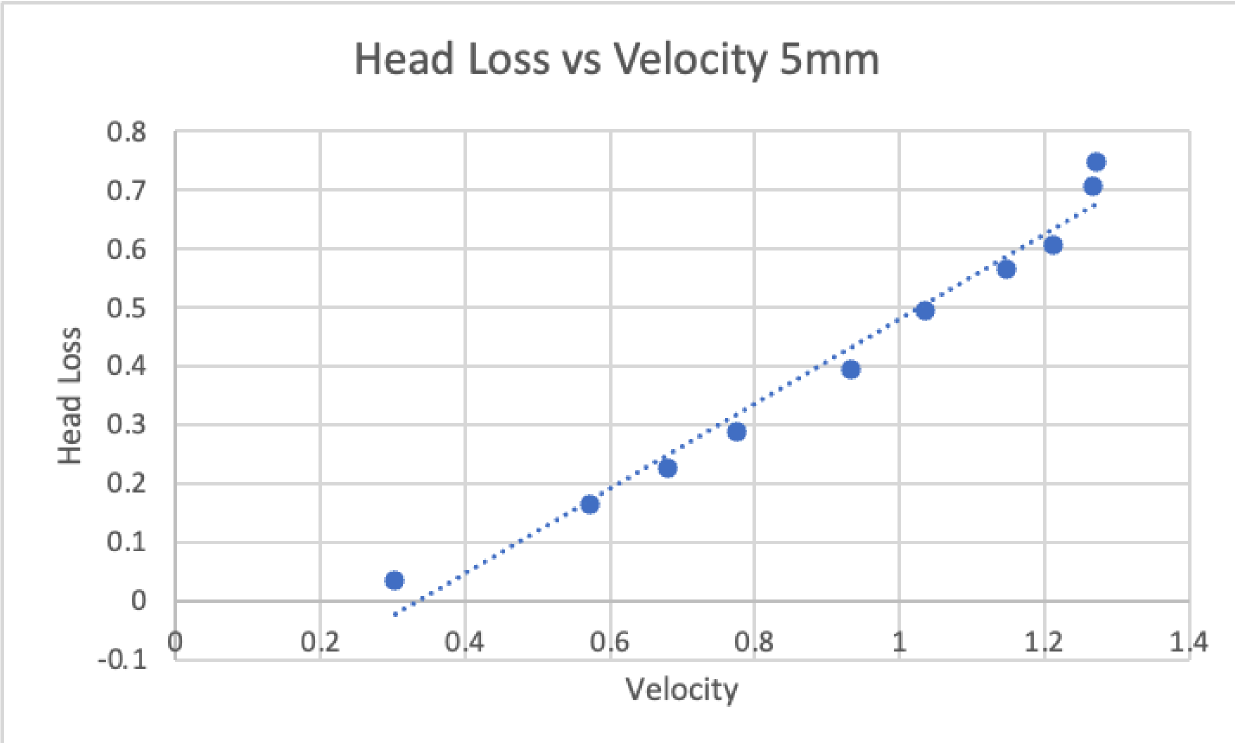


Figure 5.

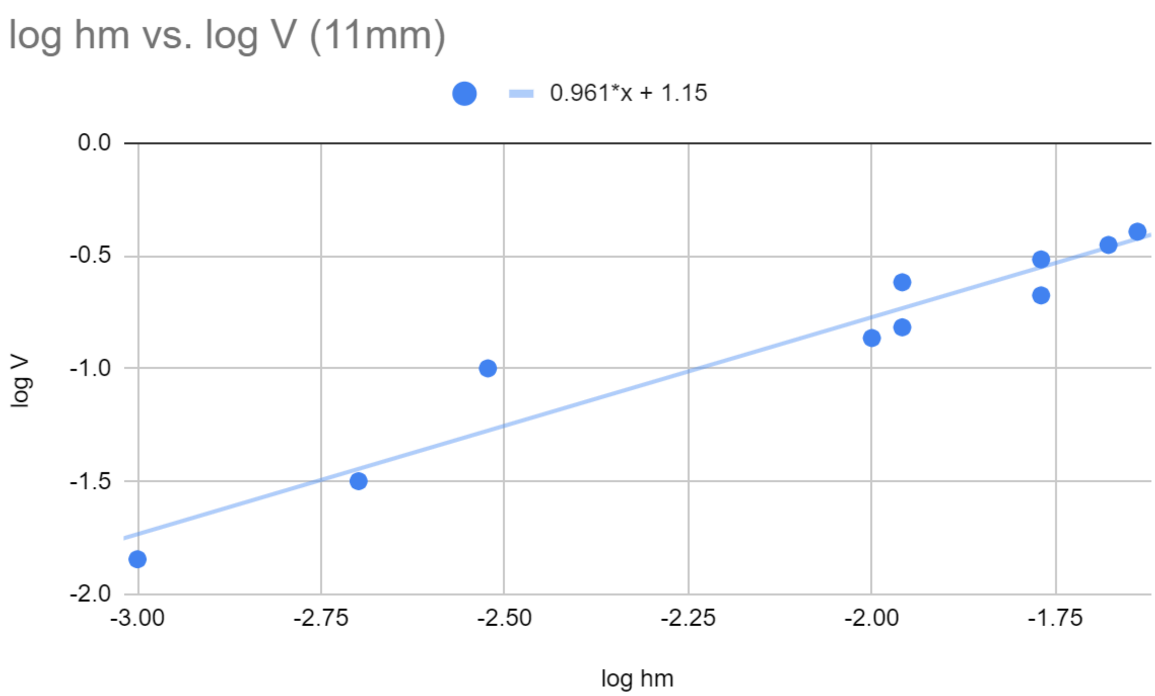


Figure 6.

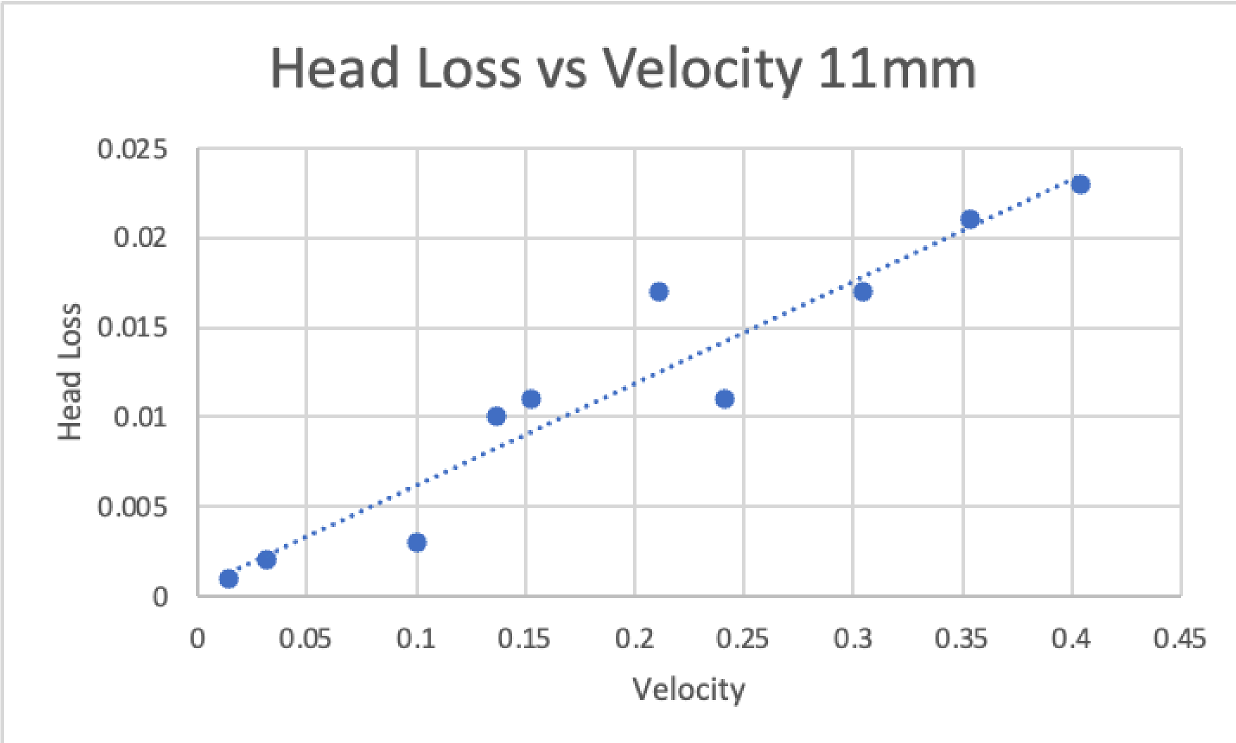


Figure 7. Smooth 11mm Pipe

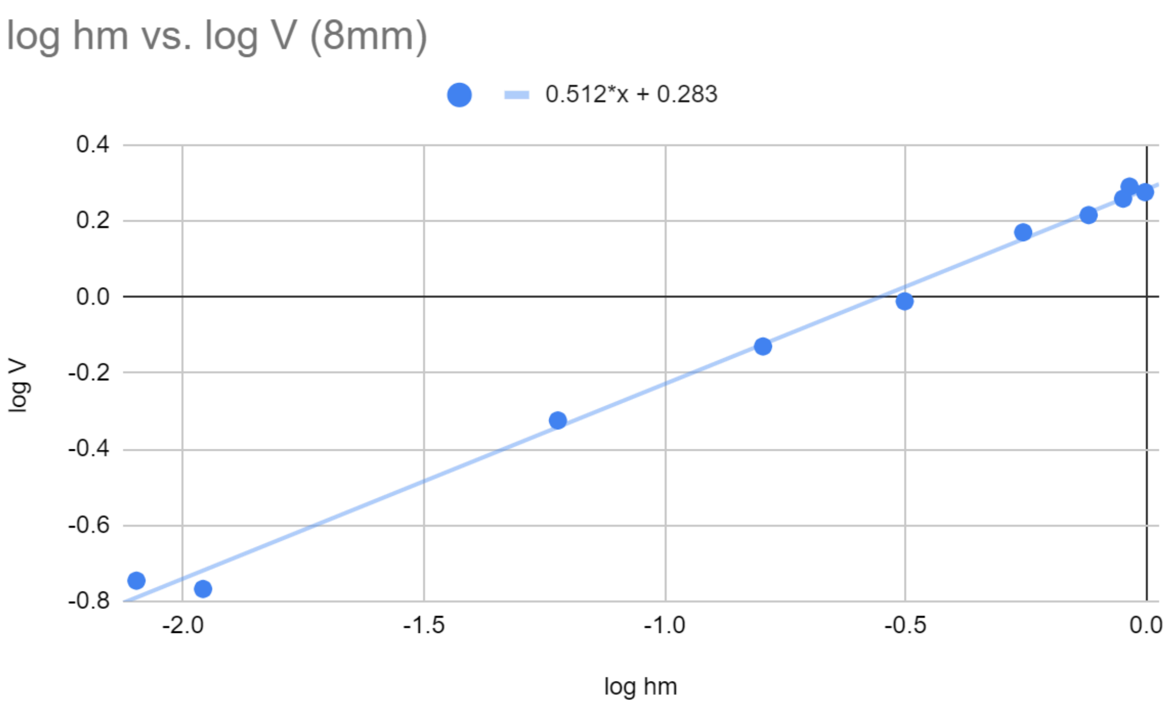


Figure 8. Smooth 8mm Pipe

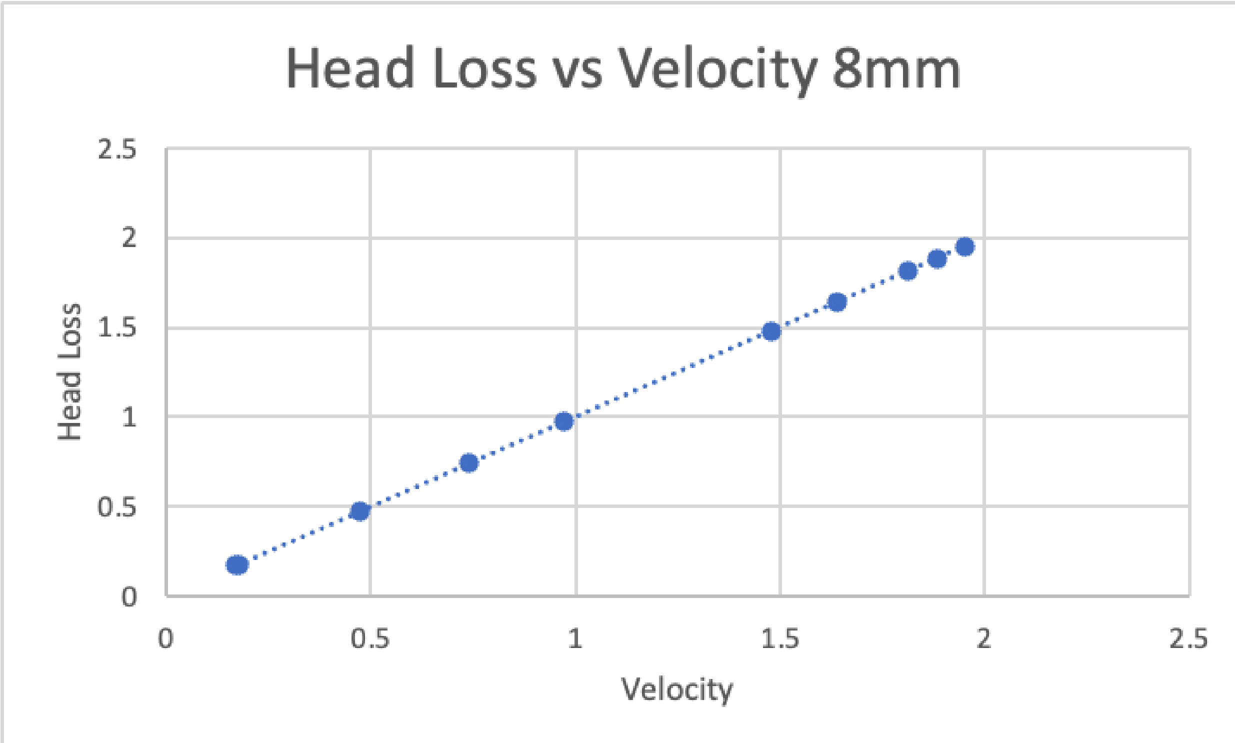


Figure 9.

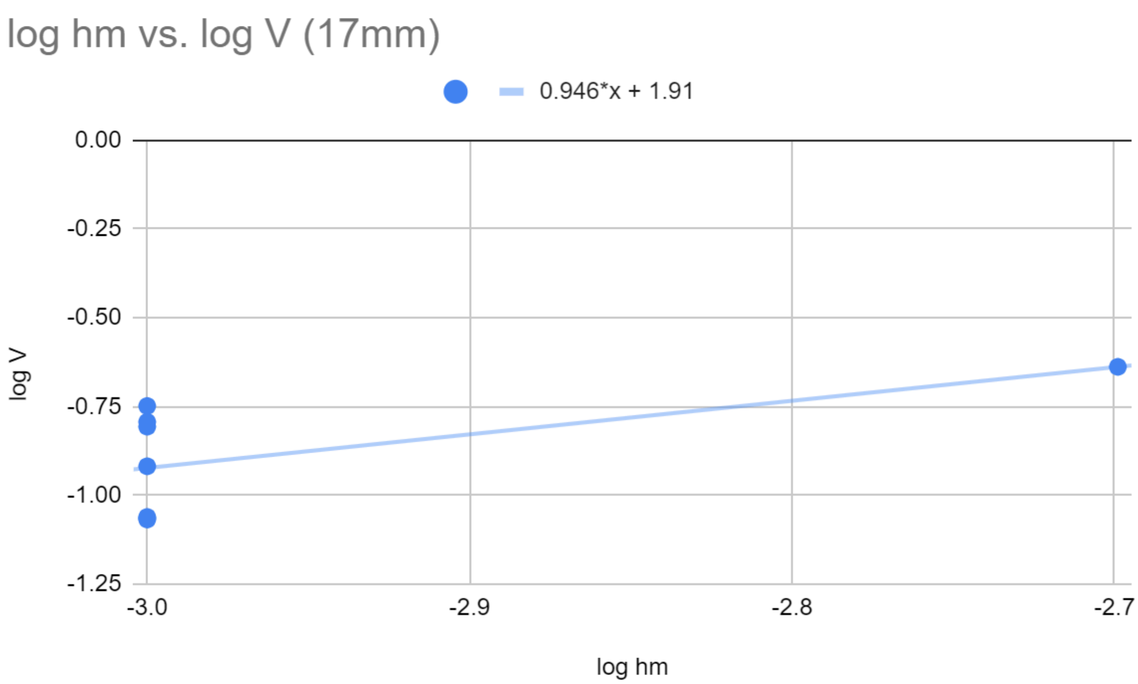


Figure 10.

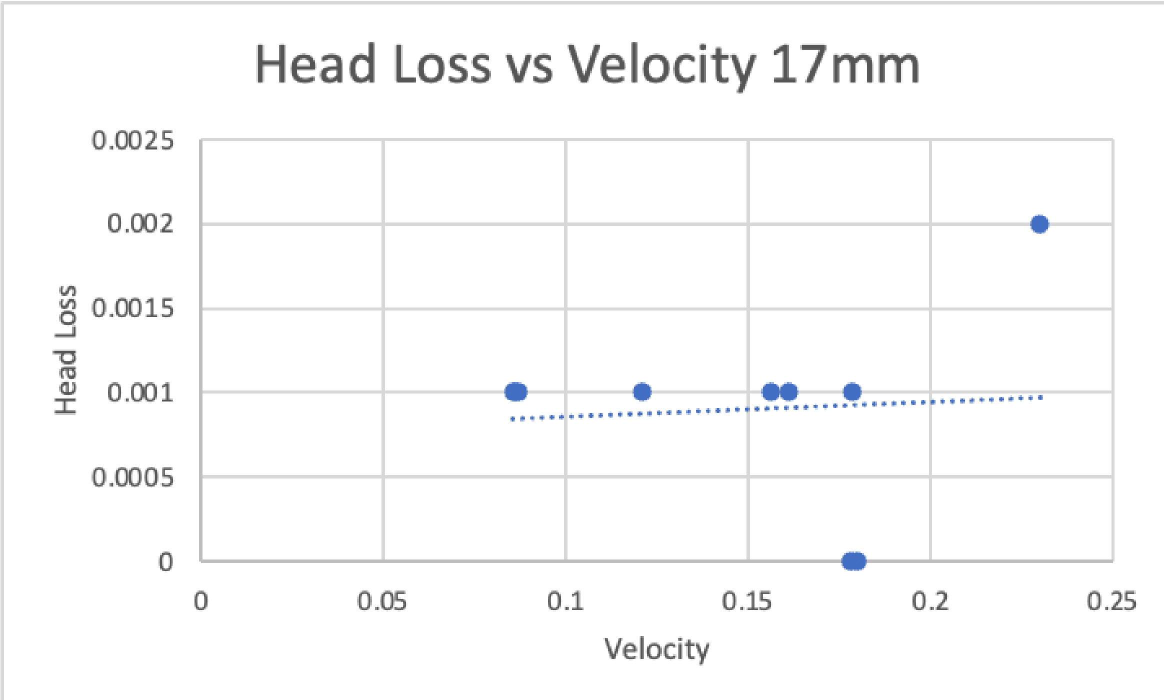


Figure 11. Smooth 17mm Pipe

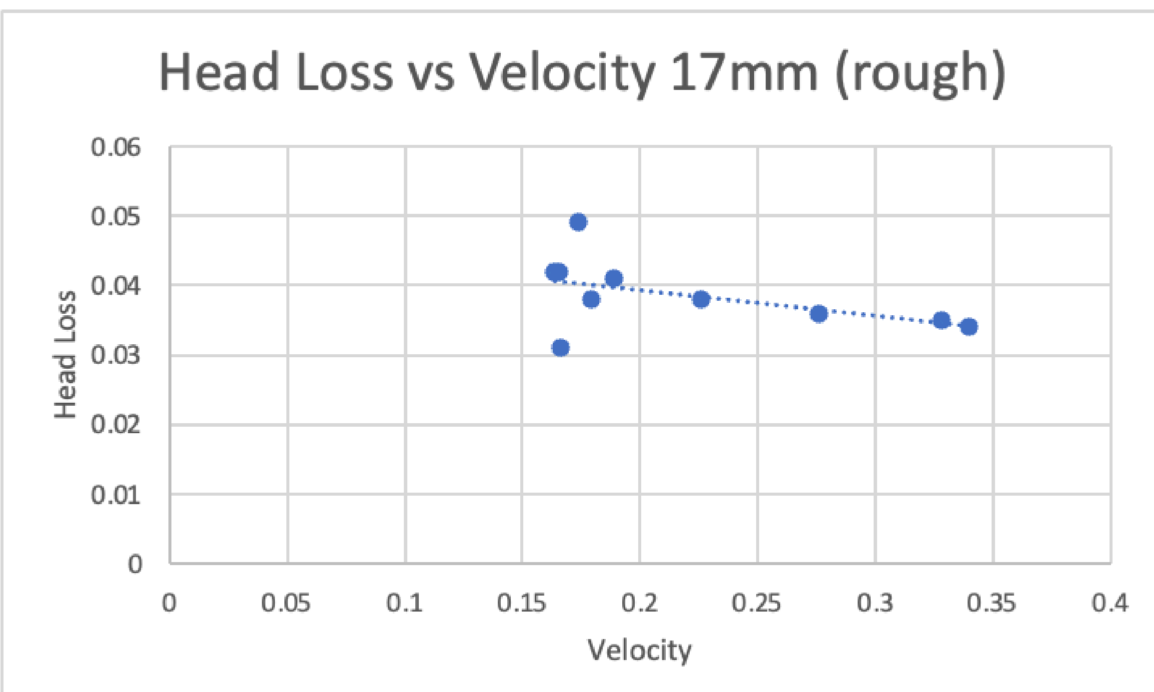


Figure 12.

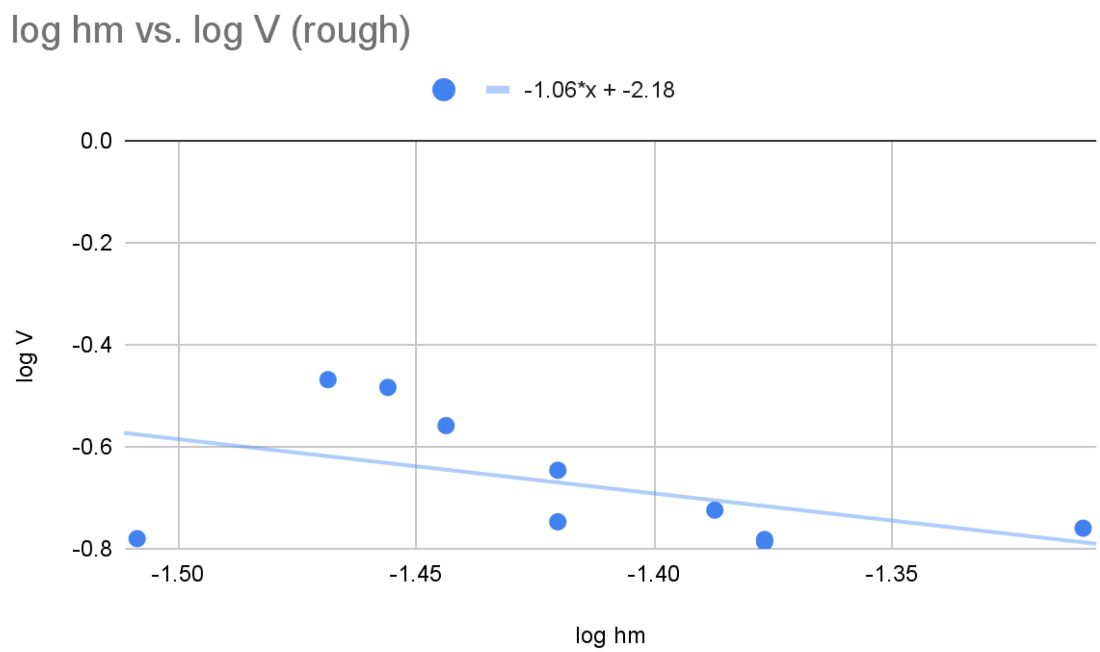


Figure 13. Rough 17mm Pipe

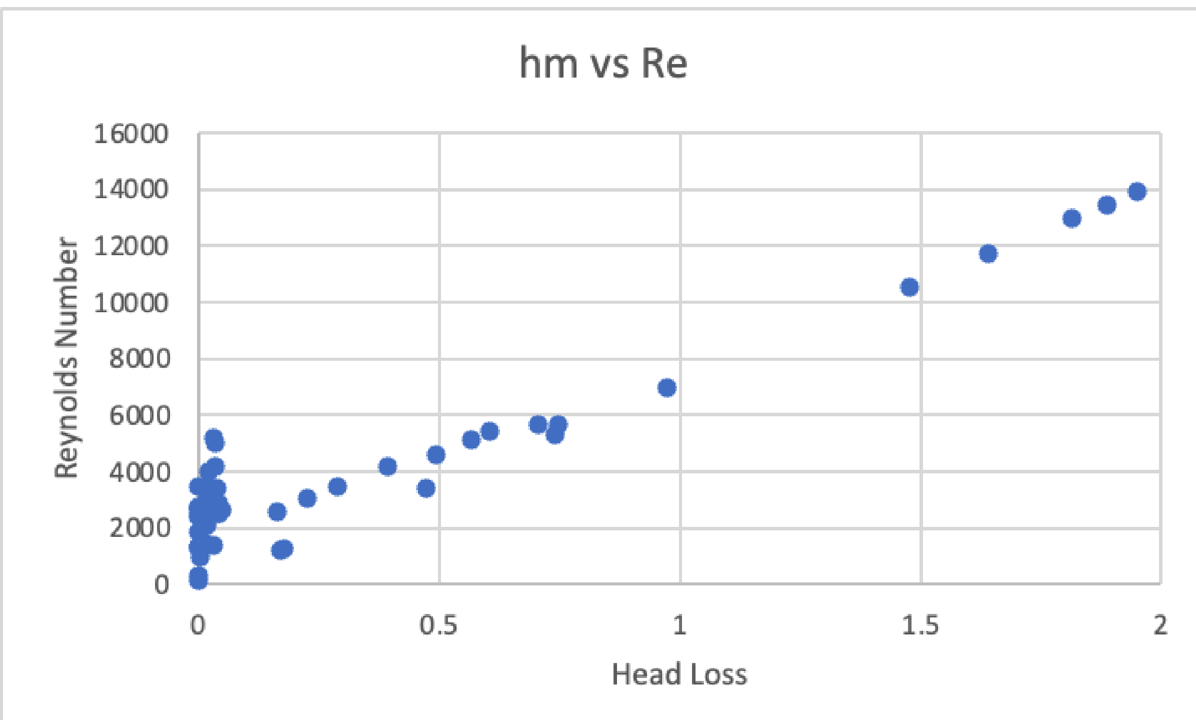
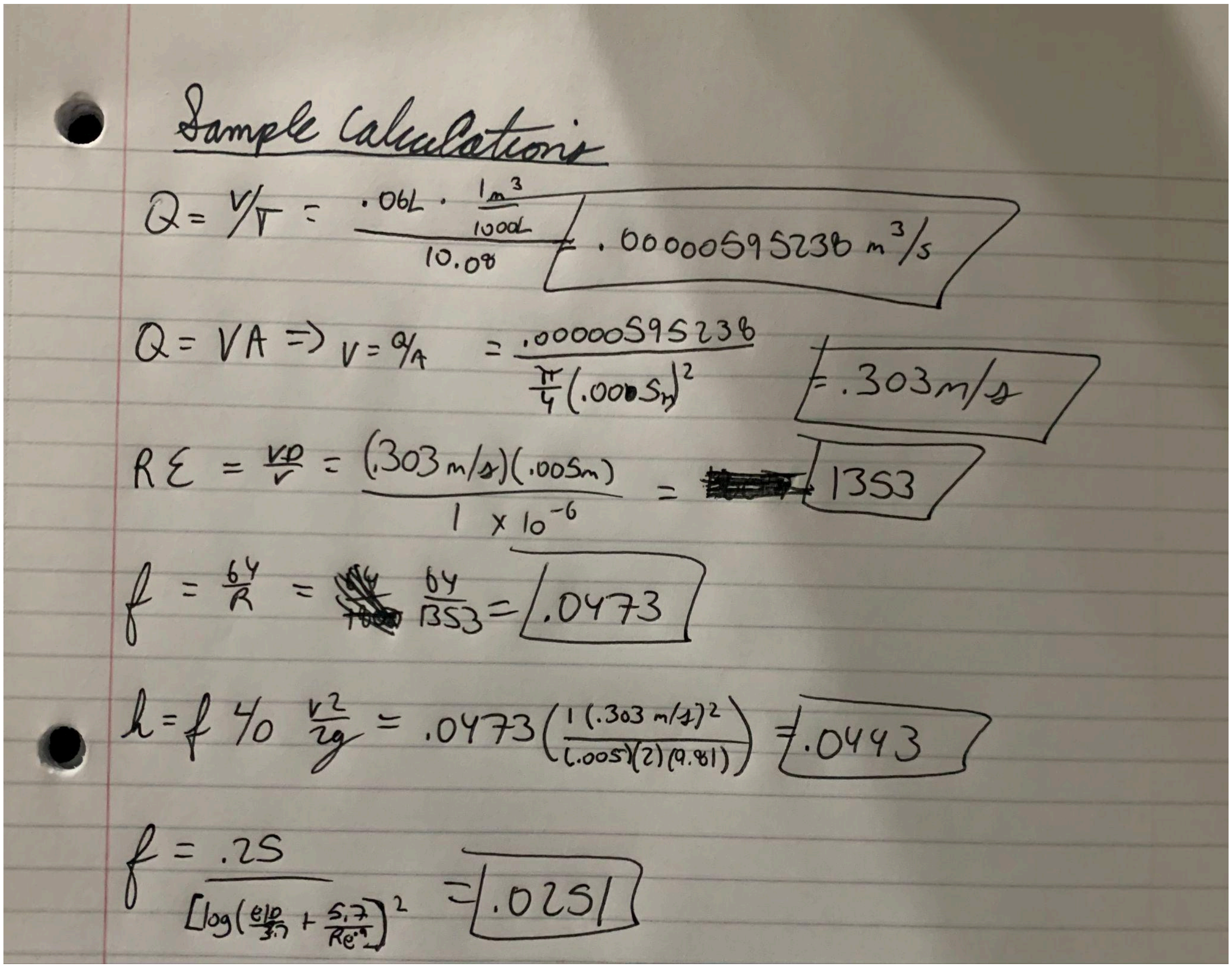


Figure 14.



Sample Calculations

$$Q = V/T = \frac{.06L \cdot \frac{1m^3}{1000L}}{10.08} = .00000595238\ m^3/s$$

$$Q = VA \Rightarrow V = Q/A = \frac{.00000595238}{\frac{\pi}{4}(.005m)^2} = .303 m/s$$

$$RE = \frac{VD}{\nu} = \frac{(.303 m/s)(.005m)}{1 \times 10^{-6}} = 1353$$

$$f = \frac{64}{R} = \frac{64}{1353} = .0473$$

$$h = f \frac{L}{D} \frac{V^2}{2g} = .0473\left(\frac{1(.303 m/s)^2}{(.005)(2)(9.81)}\right) = .0443$$

$$f = \frac{.25}{\left[\log\left(\frac{e/D}{3.7} + \frac{5.7}{Re^{.9}}\right)\right]^2} = .0251$$

1) The value of n when plotting log h_m vs. log V for the 5mm pipe was 0.479, 8mm was 0.512, 11mm was 0.961, 17mm was 0.946, and the rough pipe was -1.06. We should have expected a n value of 2, since for turbulent flow, frictional head loss is proportional to the square of the pipe velocity.

Discussion

When looking at the two head loss values, it can be determined that the calculated head loss is less than that of the measured. Also, as diameter increases, head loss will decrease when observing the data. The data was collected while trying to maintain a time measurement of 10 seconds, and see the amount of volume collected in that time using different flow rates. It is also determined that as flow rate increases, so does Reynold's number.The head loss did increase with the increasing Reynold's numbers found, and the pipe with the maximum head loss was clearly the 8mm pipe. Comparing the 17mm smooth pipe with the 17mm rough pipe it is observed that the rough experiences more head loss than the smooth due to friction.

Conclusion

The purpose of this lab is to determine the head loss and friction factor of flowing water through various pipe sizes.We observed this with turbulent and laminar flow. The head loss values were found using the Darcy-Weisbach equation. The size and roughness of the pipe is directly correlated with the flow rate of the water as seen from the data, which the larger the pipe the higher the flow rate.

References

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Houghtalen, R.J., A. O. Akan, and N. H. C. Hwang, 2009, “Fundamentals of Hydraulic Engineering Systems”, 4th edition, Prentice Hall, Chapter 3.