Fluid Mechanics (ENGR30002)
Laboratory Report

Fluid Flow in a Smooth Pipe

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ABSTRACT

The experiment investigates pressure drop variations with volumetric flow rates in a horizontal circular pipe. A log-log scale plot of Fanning friction factor (f) versus Reynolds number (Re) is plotted from the data obtained through experiment. The gradient of the line best fit through data points in the laminar region is -0.00002 which is approximately the same as the literature value.

For the maximum fluid flowrate, the velocity (V) is 3.56 m/s, Re is 45183, f is 0.0063 and head loss (h_L) 1.94 m is with all calculations shown. The values of f and h_L differ from the literature value of 0.0053 and 1.64 m respectively due to assumption of the absolute roughness of the pipe being 0 mm used in obtaining the value of f.

Using the log-log scale plot of f versus Re, the estimation of driving force required to maintain a volumetric flow of 5 x 10^{-2} m^3/s for a liquid with ρ = 1460 kg/m^3 and μ = 5.2 x 10^{-1} Ns/m^2 in a 0.1 m diameter pipe is 10454 Pa/m.

TABLE OF CONTENTS

1 AIMS

Fluid flow in a pipe is often driven by a pressure gradient. The pressure drop required to drive a flow depends on the velocity of the fluid flowing through, the viscosity of the fluid, the pipe diameter and pipe length. For a horizontal pipe with unchanging diameter, the drop in pressure across the length is solely due to friction of the fluid with the walls of the pipe. The head loss can be expressed in terms of Fanning friction factor, which is a function of the Reynolds number.

In this experiment, pressure drop is measured for varying flowrates in order to calculate the experimental values of Fanning friction factor. For laminar region, calculated f values will be compared with existing literature and any discrepancies is to be explained by error analysis.

The aims of the experiment are to investigate the variation of pressure drop with volumetric flowrate of water in a circular pipe, construct a plot of Fanning friction factor versus Reynolds number, observe the transition from laminar flow to turbulent by injecting a dye into water flowing in a pipe.

2 METHOD

2.1 SCHEMATIC DIAGRAM OF EXPERIMENTAL SET UP

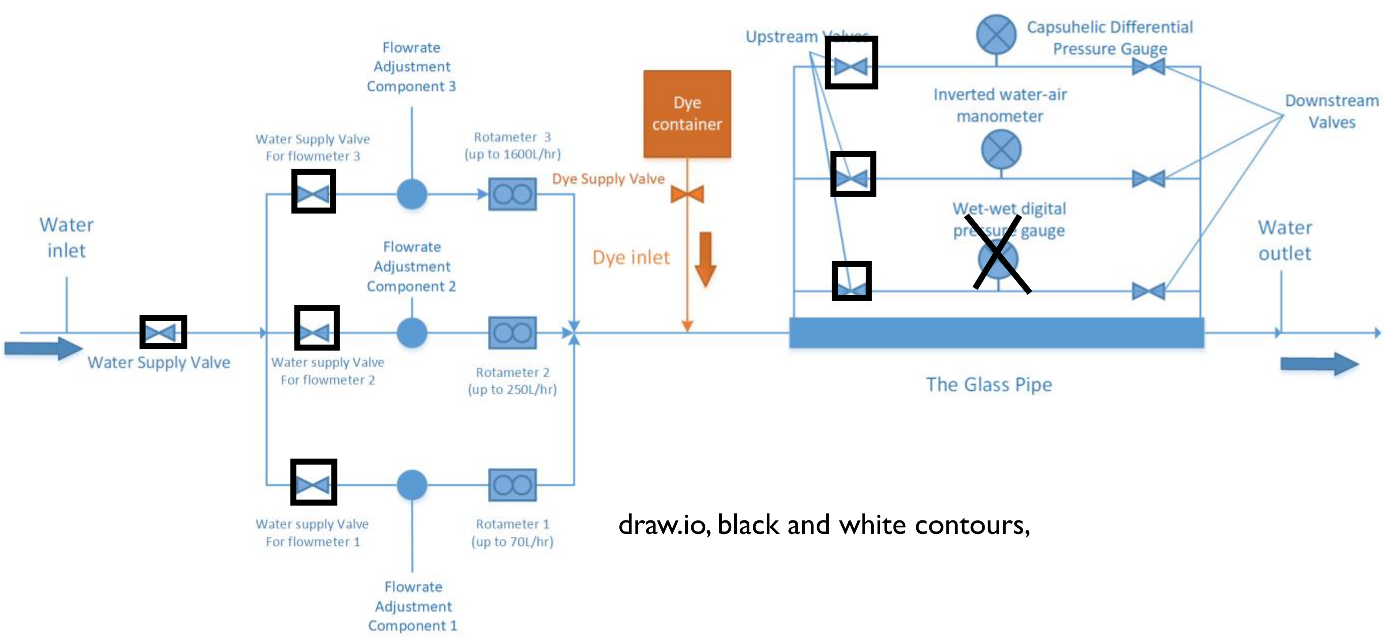

Figure 1. Schematic Diagram

2.2 EXPERIMENTAL PROCEDURE

With reference to

Figure 1. Schematic Diagram, the steps of the experimental procedure are as follow:

1. Set the apparatus following **Figure 1**.
2. Check that all gauges and flow meters are mounted safely and in the correct position.
3. Ensure all valves are set to close. All flow meters and pressure gauges should show a reading of 0 before there is any flow through the pipe.
4. Ensure tubes and gauges are free of dirt and moisture.
5. Record the pipe diameter and length of pipe.
6. Open the valves for the capsuhelic differential pressure gauge.
7. Open the valve for the smallest rotameter and set the flowrate to 10 L/hr.
8. Check for leakages.
9. Wait until pressure reading in the gauges stabilize then take measurement of the pressure drop.
10. After a measurement of the pressure drop across the pipe is taken, change the flow rate to the next desired value.
11. Repeat Step 9 after an equilibration period.
12. Increase flow rate by increments of 4 L/hr until 70 L/hr.
13. Switch to the inverted manometer pressure gauge for volumetric flow rates of 75-250 L/hr and increase by increments of 25 L/hr.
14. Switch to the wet-wet pressure gauge for volumetric flow rates of 300-1600 L/hr and increase by increments of 100 L/hr.
15. After completion of all trials, turn off the water supply.
16. Close the rotameter and pressure gauges valves.
17. Drain the water from the pipe and disconnect the inlet and outlet connections.

3 RESULTS AND DISCUSSION

3.1 LOG-LOG PLOT OF FANNING FRICTION FACTOR VERSUS REYNOLDS NUMBER

(See Appendix A: Experimental Data Calculation for full tabulated calculations relevant for this section).

The given volumetric flow rate and pressure drop measurements allow **Figure 2** to be plotted, showing relationship between Re and f in a log-log scale. The gradient of the line of best fit through the laminar flow region is found to be -0.00002.

There is a decreasing trend in f with increasing Re in the laminar flow region, followed by discontinuity in the transition flow region and another decreasing trend in the turbulent flow region.

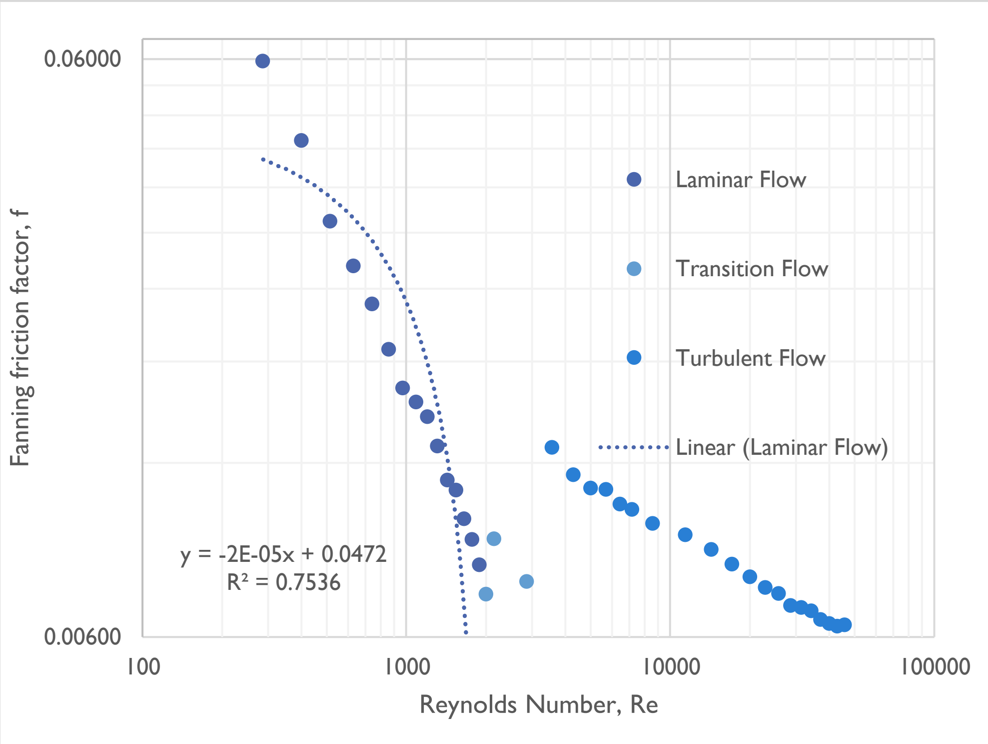

Figure 2. Experimental Log-log Scale Graph of Re Versus f

3.2 THEORETICAL RELATIONSHIP BETWEEN RE AND F IN LAMINAR FLOW

(See Appendix B: Literature Values of Fanning Friction Factor for full tabulated calculations relevant for this section).

From Lecture Notes on Pipe Flow, friction in the laminar region is independent of surface roughness and is only a function of Reynolds number and the relationship is described below,

$$f = \frac{16}{Re}$$

(Equation 1)

For 0 < Re < 2000 corresponding to laminar flow region, **Figure 3** is obtained.

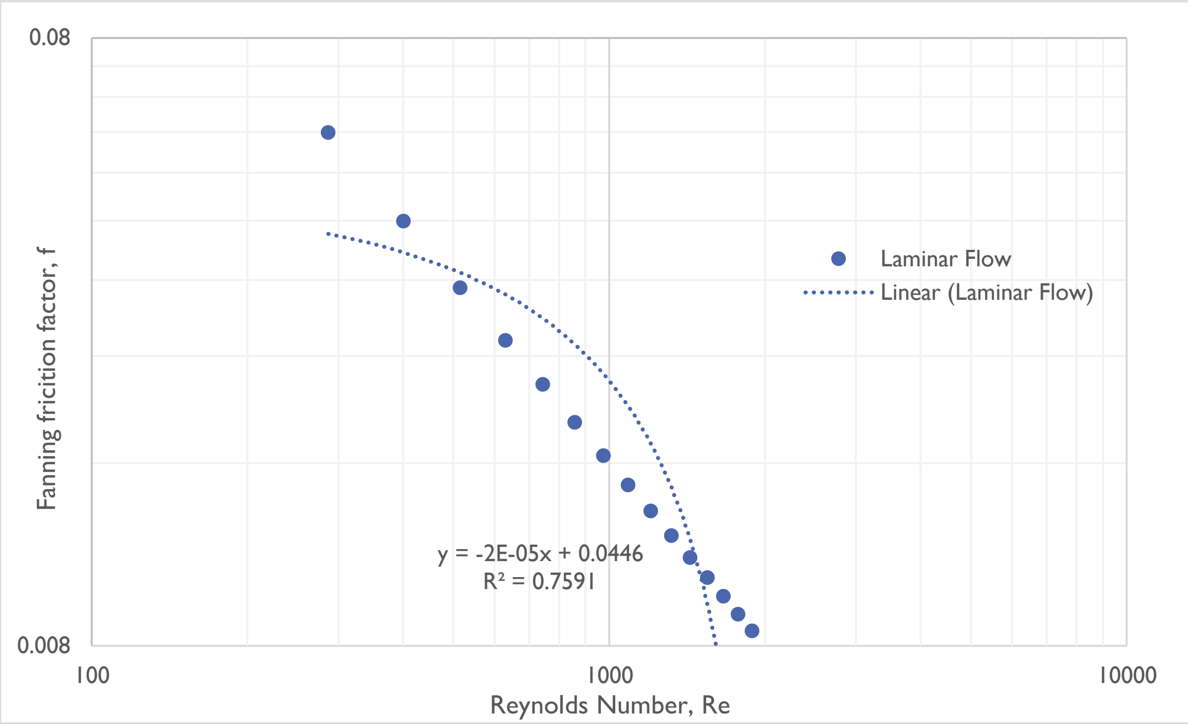

Figure 3. Theoretical Log-log Scale Graph of Re Versus f

The gradient of the line of best fit in this case is -0.00002 which approximately the same as the gradient obtained from the experimental data as shown in **Section 3.2** Theoretical Relationship Between Re and f in Laminar flow.

3.3 SAMPLE CALCULATION FOR MAXIMUM FLOW RATE (Q = 1600 L/HR)

The maximum flow rate (Q) is given to be 1600 L/hr. We can find the velocity in the direction of the flow using the equation,

$$Q = VA \implies V = \frac{Q}{A}$$

(Equation 2)

where A is the cross-sectional area of the pipe in m^2.

Cross-sectional area of the circular pipe can be obtained by the following calculation,

$$A = \frac{\pi * d^2}{4}$$

(Equation 3)

where d is the diameter of the pipe in m.

In the Laboratory Instruction, d is given to be 0.0126 m and therefore the velocity is,

$$V = \frac{1600\frac{L}{h} * \frac{1\ m^3}{1000\ L} * \frac{1\ h}{3600\ s}}{\pi * \frac{(0.0126\ m)^2}{4}}$$

$$\approx 3.56\ m/s$$

And the Reynolds number is,

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

(Equation 4)

where ρ is the density of water in kg/m^3 and μ is the viscosity of water in $Pa\ s$ evaluated at 21℃ ("Viscosity of Water – viscosity table and viscosity chart :: Anton Paar Wiki", 2020).

$$Re = \frac{998\frac{kg}{m^3} * 3.56\frac{m}{s} * 0.0126\ m}{0.009775\ Pa\ s}$$

$$\approx 45813 \gg 3000$$

As the Re is far greater than 3000, the flow in the pipe at the maximum flow rate is categorized as turbulent.

The experimental value of f is obtained through the equations given in the Laboratory Instructions,

$$h_L = \frac{P_1 - P_2}{\rho g}\ \&\ h_L = \frac{2fLV^2}{dg}$$

(Equation 5 & 6)

where L is the length of the pipe in m and g is the acceleration due to gravity in m/s^2.

The value of head loss in this case is,

$$h_L = \frac{19000\ Pa}{998\ kg/m^3\ * 9.8\ m/s^2}$$

$$\approx 1.94\ m$$

(Equation 5 & 6) can be rearranged to have f as the subject,

$$f = \frac{d * \frac{P_1 - P_2}{\rho}}{2LV^2}$$

(Equation 7)

As all the value of the parameters are known,

$$f = \frac{0.0126\ m * \frac{19000\ Pa}{998\ kg/m^3}}{2 * 1.5\ m * (3.54\ m)^2}$$

$$\approx 0.0063$$

For theoretical value of f, it is assumed that the glass pipe is a smooth pipe which has an absolute roughness (ε) of 0 mm. With the known Re, we can use the Moody Diagram (**Figure 4**) and the curve for smooth pipe to find the corresponding theoretical f value. In this case, the value of Fanning friction factor is 0.0053.

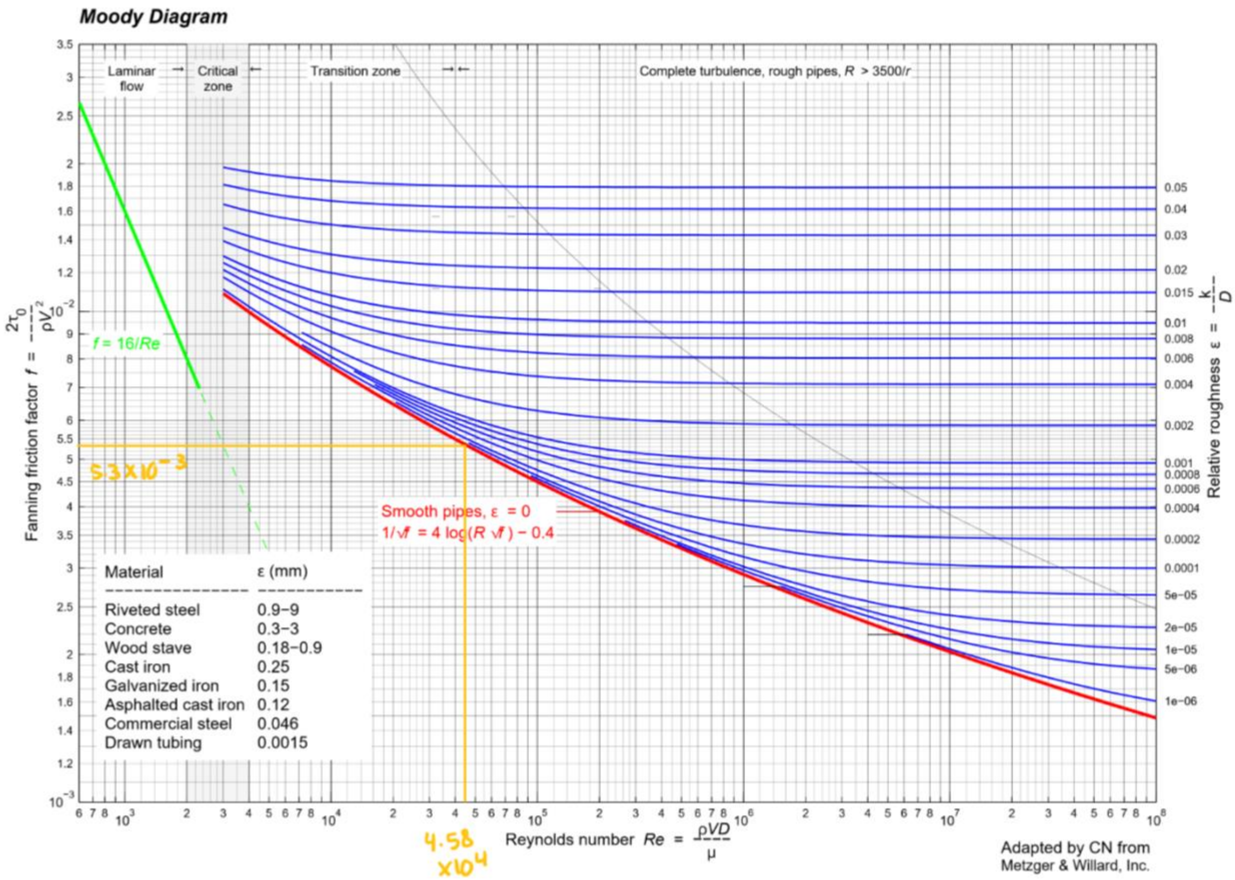

Figure 4. Moody Diagram

Theoretical head loss can also be calculated using **(Equation** 5 & 6).

$$h_L = \frac{2 * 0.053 * 1.5\, m * (3.54\, m)^2}{0.0126\, m * \ 9.8\, m/s^2}$$

$$\approx 1.64\, m$$

The calculations above show that the theoretical results of both Fanning friction factor and head loss differ from the experimental data.

For the Fanning friction factor,

$$\%\, difference = \left|\frac{f_{predictive} - f_{experimental}}{f_{predictive}}\right| x\ 100\%$$

(Equation 8)

$$= \left|\frac{0.0053 - 0.0063}{0.0053}\right| x\ 100\%$$

$$\approx 18.9\%$$

For the head loss,

$$\%\ difference = \left|\frac{h_{L,predictive} - h_{L,experimental}}{h_{L,predictive}}\right| x\ 100\%$$

(Equation 9)

$$= \left|\frac{1.64 - 1.94}{1.64}\right| x\ 100\%$$
$$\approx 18.3\%$$

The percentage differences above are of similar value as f is directly proportional to h_L. The results of the theoretical calculation do not agree well with the experimental values, which experimental values of both f and h_L being higher than the theoretical.

As shown in the Moody diagram (**Figure 4**), for a constant Re, the Fanning friction factor is proportional to the relative roughness of the pipe. The assumption of smooth pipe gives a smaller f when compared to the value that the experimental results demonstrates, indicating that the ε of the glass pipe is higher than 0. In practice, glass pipe can have ε ranging from 0.0015 to 0.01 mm ("Absolute Roughness of Pipe Material | Neutrium", 2020) according to the manufacturing specifications. Since the head loss is calculated from the f, lower f gives a lower h_L.

3.4 DRIVING FORCE ESTIMATION FOR ANOTHER LIQUID

The volumetric flow of the liquid is given to be $5\ x\ 10^{-2}\ m^3/s$ flowing through a smooth pipe of diameter 0.1 m. Using **(Equation** 2), the average velocity of liquid flowing through the pipe is,

$$V = \frac{5\ x\ 10^{-2}\ m^3/s}{\pi * \frac{(0.1\ m)^2}{4}}$$
$$\approx 6.37\ m/s$$

The fluid properties are provided as $\rho = 1460\ kg/m^3$ and $\mu = 5\ .2x\ 10^{-1}\ Ns/m^2$. Therefore, the Reynolds number can be calculated through **(Equation** 4).

$$Re = \frac{1460\ kg/m^3\ * 6.37\ \text{m/s}\ * 0.1\ \text{m}}{5\ .2x\ 10^{-1}\ Ns/m^2}$$
$$\approx 1787$$

From Appendix A: Experimental Data Calculation, **Table A 1** contains the following data which was used to plot **Figure 2**. Based on this, the Fanning friction factor for this flow of viscous liquid is approximately 0.00882.

Table A. Excerpt from Table A 1.

Flowrate (L/hr)	Flowrate (m3/s)	v (m/s)	Re	ΔP (Pa)	$\frac{\Delta P}{\rho}$ (J/kg)	f
62	1.72E-05	0.14	1777	40	0.040	0.00882

The driving force in terms of the pressure drop per unit length of the pipe can be obtained by rearranging **(Equation 5 &** 6).

$$\frac{P_1 - P_2}{L} = \frac{2fV^2\rho}{d}$$

$$= \frac{2 * 0.00882 * \ (6.37 \text{ m/s})^2 * 1460\ kg/m^3}{0.1\ m}$$

$$\approx 10454\ Pa/m$$

This shows that the driving force per unit length to maintain the flow rate of viscous liquid specified is 10454 Pa/m or 10.5 kPa/m.

4 CONCLUSION

The pressure drop in a horizontal, circular, smooth pipe is investigated with flow rates of water varying from 10-1600 L/h. Three pressure gauges are utilized to measure the drop in pressure, each one used accordingly to the flow rate through the pipe and their capacities to maximize accuracy of reading. Measurements of flow rate and pressure drop allows the values of velocity, Reynolds number, Fanning friction factor, and the head loss to be calculated using equations derived from the Bernoulli equation.

In the laminar region of the flow of the experiment, the relationship between Fanning friction factor and Reynolds number agree with the literature value as seen from the gradients of the line best fit. However, in the turbulent region, Fanning friction factor not only a function of the Reynolds number but also of the relative roughness of the pipe. The assumption that the value of $\frac{\varepsilon}{d}$ is equal to 0 leads to a 18.9% difference with the theoretical value being lower, which suggests that the relative roughness is greater than the assumed value. For a more accurate estimation of the theoretical Fanning friction factor, the absolute roughness of the glass pipe should be obtained from the manufacturer.

The log-log scale plot of Re versus f is employed in the calculation of a hypothetical flow involving a viscous liquid to find the pressure drop per unit length required as the driving force for the flow.

5 REFERENCES

Viscosity of Water – viscosity table and viscosity chart :: Anton Paar Wiki. (2020). Retrieved 10 September 2020, from https://wiki.anton-paar.com/au-en/water/

Absolute Roughness of Pipe Material | Neutrium. (2020). Retrieved 10 September 2020, from https://neutrium.net/fluid-flow/absolute-roughness-of-pipe-material/

6 APPENDICES

APPENDIX A: EXPERIMENTAL DATA CALCULATION

Table A 1. Experimental Data

Flowrate (L/hr)	Flowrate (m^3/s)	v (m/s)	Re	Δh (cm)	ΔP (Pa)	$\frac{\Delta P}{\rho}$ (J/kg)	h_L (m)	f
10	2.78E-06	0.02	287		7	0.007	0.0007	0.05936
14	3.89E-06	0.03	401		10	0.010	0.0010	0.04326
18	5.00E-06	0.04	516		12	0.012	0.0012	0.03141
22	6.11E-06	0.05	630		15	0.015	0.0015	0.02628
26	7.22E-06	0.06	745		18	0.018	0.0018	0.02258
30	8.33E-06	0.07	860		20	0.020	0.0020	0.01884
34	9.44E-06	0.08	974		22	0.022	0.0022	0.01614
38	1.06E-05	0.08	1089		26	0.026	0.0027	0.01527
42	1.17E-05	0.09	1204		30	0.030	0.0031	0.01442
46	1.28E-05	0.10	1318		32	0.032	0.0033	0.01282
50	1.39E-05	0.11	1433		33	0.033	0.0034	0.01119
54	1.50E-05	0.12	1548		37	0.037	0.0038	0.01076
58	1.61E-05	0.13	1662		38	0.038	0.0039	0.00958
62	1.72E-05	0.14	1777		40	0.040	0.0041	0.00882
66	1.83E-05	0.15	1891		41	0.041	0.0042	0.00798
70	1.94E-05	0.16	2006		41	0.041	0.0042	0.00710
75	2.08E-05	0.17	2149	0.6	59	0.059	0.0060	0.00885
100	2.78E-05	0.22	2866	0.9	88	0.088	0.0090	0.00746
125	3.47E-05	0.28	3582	2.4	235	0.235	0.0240	0.01274
150	4.17E-05	0.33	4299	3.1	303	0.304	0.0310	0.01143
175	4.86E-05	0.39	5015	4.0	391	0.392	0.0400	0.01083
200	5.56E-05	0.45	5732	5.2	509	0.510	0.0520	0.01078
225	6.25E-05	0.50	6448	6.2	606	0.608	0.0620	0.01016
250	6.94E-05	0.56	7165	7.5	734	0.735	0.0750	0.00995
300	8.33E-05	0.67	8597		1000	1.002	0.1022	0.00942
400	1.11E-04	0.89	11463		1700	1.703	0.1738	0.00901
500	1.39E-04	1.11	14329		2500	2.505	0.2556	0.00848
600	1.67E-04	1.34	17195		3400	3.407	0.3476	0.00801

700	1.94E-04	1.56	20061		4400	4.409	0.4499	0.00761
800	2.22E-04	1.78	22927		5500	5.511	0.5623	0.00729
900	2.50E-04	2.00	25792		6800	6.814	0.6953	0.00712
1000	2.78E-04	2.23	28658		8000	8.016	0.8180	0.00678
1100	3.06E-04	2.45	31524		9600	9.619	0.9816	0.00673
1200	3.33E-04	2.67	34390		11300	11.323	1.1554	0.00665
1300	3.61E-04	2.90	37256		12800	12.826	1.3087	0.00642
1400	3.89E-04	3.12	40122		14600	14.629	1.4928	0.00632
1500	4.17E-04	3.34	42987		16600	16.633	1.6973	0.00626
1600	4.44E-04	3.56	45853		19000	19.038	1.9427	0.00629

APPENDIX B: LITERATURE VALUES OF FANNING FRICTION FACTOR

Table B 1. Re and Theoretical f in Laminar Flow Regime

Re	f
287	0.05583
401	0.03988
516	0.03102
630	0.02538
745	0.02147
860	0.01861
974	0.01642
1089	0.01469
1204	0.01329
1318	0.01214
1433	0.01117
1548	0.01034
1662	0.00963
1777	0.00900
1891	0.00846