MECH2670: Thermofluids 2

REAL INTERNAL AND EXTERNAL FLOW
Energy Losses in Pipe FLow

Harry Fotheringham
Student ID: 201419355

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University Name: University of Leeds
Country: England
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Contents

1 Introduction

Within Fluid pipe flow there are many different ways that energy can be lost from the fluid. This experiment looks into just two different ways of energy loss. This two ways can be split into two different types of energy loss: *major* and *minor* energy losses. The major losses explored in this lab are losses due to friction in the pipe which involves the use of a rough pipe and a smooth pipe. The minor losses involves two different types of pipe bend. Specifically a 90° mitre elbow and a 90° long radius bend.

1.1 Aims

The main outcome of the major loss experiment was to determine the relationship between the energy losses in the pipe compared to the fluid flow. Also to observe the effect the friction factor had on Reynolds number in the two different pipe frictions. There was a similar aim for the minor losses but instead of finding the effect of friction finding the effect of the different pipe bends. [1]

1.2 Theory

1.3 Head Loss

1.3.1 Reynolds Number

To find out the type and level of flow of the liquid (laminar or turbulent), Reynolds number (R_e) can be used to give us an idea on this property. It is calculated using equation 1 [3, Page. 360]. If R_e is less than 2000, then the flow can be considered to be laminar, if it is greater than 4000 then the flow is considered turbulent and anywhere between these values the flow is considered in transition.

$$R_e = \frac{\rho \bar{U} D}{\eta} \tag{1}$$

Where,
ρ = Density of the fluid [Kg/m^3]
$\bar{U}$ = Fluid flow velocity [m/s]
D = Diameter of the pipe [m]
η = Dynamic viscosity [Pa.s]
[1]Reynold also demonstrated the relationship between the major losses of a fluid and its velocity. He found that:

- $h_L \; \alpha \; \bar{U}$ - at a low R_e number (laminar flow)
- $h_L \; \alpha \; \bar{U}^n$ - at high R_e number (turbulent flow), where n is a constant

1.4 Major Losses

Major losses, h_L, in a pipe from a flowing fluid are the energy losses which occur due to friction between the fluid and the surface of the pipe. They can be calculated using Equation 2. [3, Page. 426]

$$h_L = f \frac{L}{D} \frac{\bar{U}^2}{2g} \tag{2}$$

Where,
f = Friction Factor
$\bar{U}$ = Fluid flow velocity [m/s]
D = Diameter of the pipe [m]
L = Length of the pipe [m]
g = Acceleration due to gravity [m/s^2]

1.5 Minor Losses

Minor losses, h_M, within a fluid are those which are caused by changes in the pipe, whether that be a bend or a shrinkage in pipe diameter. Minor losses of a fluid are calculated using Equation 3. [3, Pages. 430-1]

$$h_M = K_L \frac{\bar{U}^2}{2g} \tag{3}$$

Where,
K_L = Loss Factor
$\bar{U}$ = Fluid flow velocity [m/s]
g = Acceleration due to gravity [m/s^2] K_L is strongly dependent on the actual geometry of the pipe, specifically in this case the angle and diameter of the pipe bends. It is also affected by the type of flow through the pipe, whether that be turbulent or laminar. Therefore K_L can be summed up as follows [3, Page. 431].

$$K_L = \phi(geometry, R_e) \tag{4}$$

2 Methodology

2.1 Apparatus and Set-up

The apparatus used for the experiment is listed below:

- Stop watch
- Vernier calliper
- Manometer
- Measuring cylinder

Using all this apparatus and the pipe frame, the set up is shown below in Figure 1

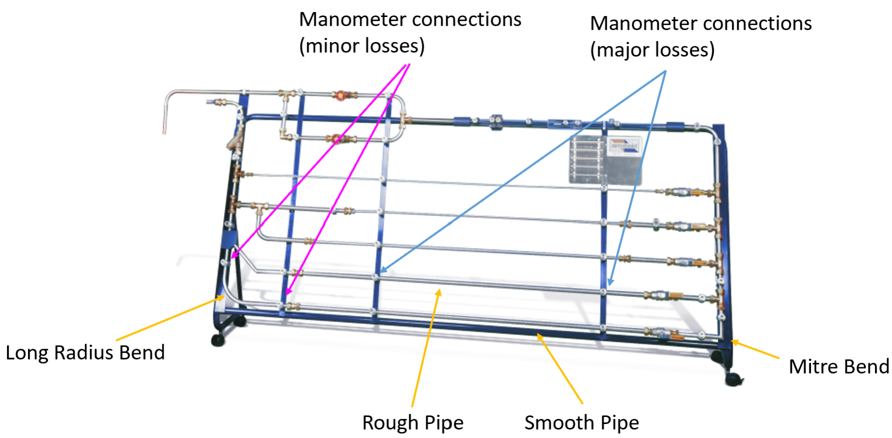

Figure 1: Image of the experimental setting labelling each of the points in the pipes used for each experiment. Including where to connect the manometer

2.2 Procedure

Step one of this experiment after setting up the equipment as shown in Figure 1 is to turn on the flow from the hydraulic bench. On the hydraulic bench is a dial which controls the flow rate of the water throughout. Once the water is flowing through the pipe system it will come out of the tap and a measuring cylinder can be used to collect a volume of water in a measured period of time. From this the flow rate can be calculated. To measure the time a stopwatch is started and stopped when the cylinder is placed in the stream of water and taken out respectively. As well as finding the flow rate, the head loss is the other main variable in this experiment. This can be found by measuring the heights of the liquid in the two vertical manometer tubes connected to either end of the pipe or bend. The difference between these two values then represents the head loss between the beginning and end of the pipe. After one iteration, the dial on the hydraulic bench can be turned to another flow rate and then the same practice completed. This was repeated 8 times to provide an accurate data set. Once completed, turn the flow rate low and take out the connecting tubes of the manometer and reattach to the other pipe and then across the pipe bends. so no water escapes when changing the manometer tubes. Also at some point during the experiment the calliper is used placed inside the pipes used to measure their diameter.

2.3 Data Analysis

The data collected in its raw form is made up of time and volume, two properties that can be used to find the flow rate of the fluid. To do this equation 5 is used. At each different flow rate the head loss is measured by reading the value on each manometer connected to two sections of the pipe. These can once again be converted into the head loss of the pipe, which is done using equation 6

$$Q = V/t \tag{5}$$

$$h_1 - h_2 = h_L \tag{6}$$

Starting with the Major losses, to find out the type of flow of the liquid (laminar - turbulent), Reynolds number (R_e) is used. It is calculated using equation 1. This allows us to see whether the flow is more turbulent at higher or lower flow velocities. Next is to find the friction factor of each of the pipes using the major losses equation (2). Then when these values have been obtained for each different flow rate they are plotted together on the moody diagram shown in Figure 4. And reading from the graph the relative roughness of each pipe can be found. Finally the roughness of each pipe can be found using the equation below, Equation 7

$$Roughness, \varepsilon = Relative\ roughness \times D \tag{7}$$

Following on, for the minor losses across the bends, the loss factor can be worked out using the minor losses equation (3) so that it can be compared to the flow rate in the pipe.

3 Results

3.1 Pipe Roughness

The following data contains all of the results and calculations from the first two steps of the experiment; measuring the energy loss from friction in the pipe.
Tables 1 and 2 contain all of the data relating to the smooth and rough pipe respectively. The friction factor and Reynolds number are also shown in these tables, which have been calculated from the known information above. Further from this table the fluid velocity $\bar{U}$ can be calculated by multiplying the volumetric flow rate by the cross-sectional area of the respective pipe. The diameter for the pipes are 16mm for the rough pipe and 17mm for the smooth pipe.

Table 1: Smooth Pipe Data

Volume (ml)	Time (s)	Volumetric Flow Rate (cm^3/s)	h_1(mm)	h_2 (mm)	Head Loss (mm)	Friction Factor	Reynolds Number $\times 10^3$
150	39.99	3.751	353	350	3	3.664	0.2440
310	14.41	21.51	354	350	4	0.1485	1.400
330	13.35	24.72	353	351	2	0.05625	1.608
475	12.81	37.08	355	351	4	0.04999	2.413
830	12.64	65.66	343	335	8	0.03188	4.272
2000	15.17	131.8	375	330	45	0.04449	8.578
3300	15.17	217.5	417	325	92	0.03341	14.153
6000	16.45	364.7	518	310	208	0.02687	23.73

Table 2: Rough Pipe Raw Data

Volume (ml)	Time (s)	Volumetric Flow Rate (cm^3/s)	h_1(mm)	h_2 (mm)	Head Loss (mm)	Friction Factor	Reynolds Number $\times 10^3$
165	33.19	4.971	350	330	20	10.27	0.344
370	14.87	24.88	351	329	22	0.4509	1.720
725	12.97	55.90	347	328	19	0.07717	3.864
695	11.35	61.23	350	328	22	0.07446	4.233
985	12.74	77.35	360	323	37	0.07855	5.345
2000	17.82	112.2	416	298	118	0.1189	7.759
2500	13.77	181.6	510	240	270	0.1040	12.55
3000	10.7	280.4	769	80	689	0.1112	19.38

The graphs below shows a graphical representation if the data obtained from the experiment. With a clear linear region in the beginning as expected and a more irrational relationship later on, especially in the rough pipe. As shown earlier (section 1.3.1) the relationships between the flow rate and the head loss is proportional for laminar flow. Whereas head loss is proportionate to the flow rate to the order of n. To determine the value of n the natural log of the flow rate and head loss have been taken an plotted in Figure 3. As such the turbulent flow has become more linear and so n can be calculated from the gradient at this point.

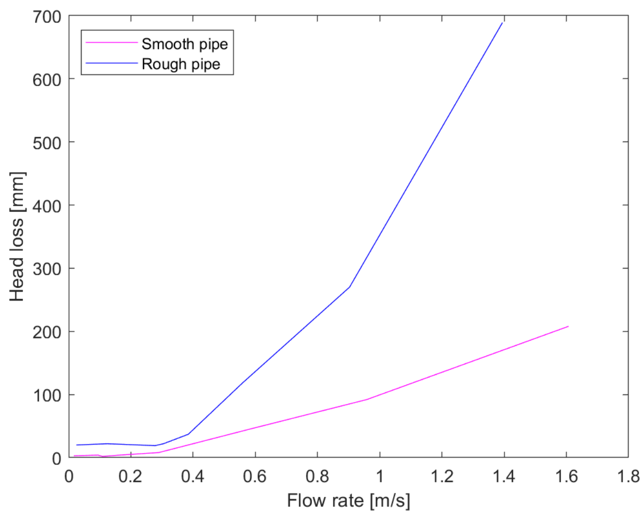

Figure 2: Graph displaying the relationship between the flow rate[m/s] of the fluid and the head loss[mm]. The legend shows which pipe the two lines represent. It is clear from the graph that the head loss in the rough pipe was more predominant than in the smooth pipe.

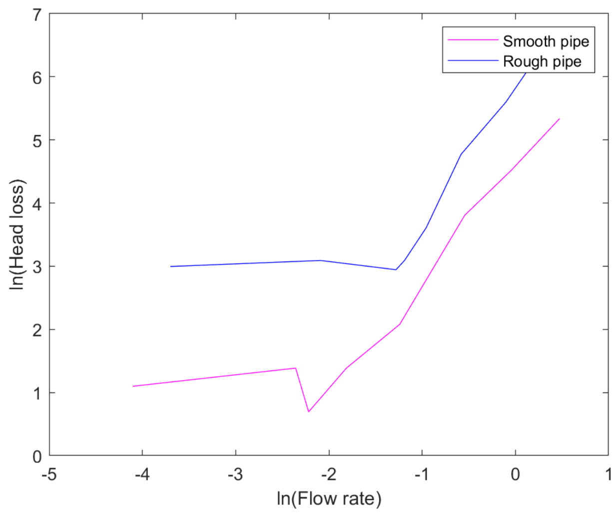

Figure 3: A graph to show the relationship between the natural log of both the flow rate and the head loss in the manometer. From this graph the gradient of the linear section of the graph can be found. For the Rough Pipe, n = 2.27 and for the Smooth Pipe, n = 1.77.

Finally, for the major losses results, is the moody diagram. Plotted on there is the results from Tables 1 and 2. By looking at these plots two results for the relative roughness of each of the pipes can be drawn. Then from the relative roughness, the equivalent roughness of each of the pipes can be found. For the Smooth pipe $\varepsilon \approx 0.034mm$ and for the Rough pipe $\varepsilon \approx 0.8mm$

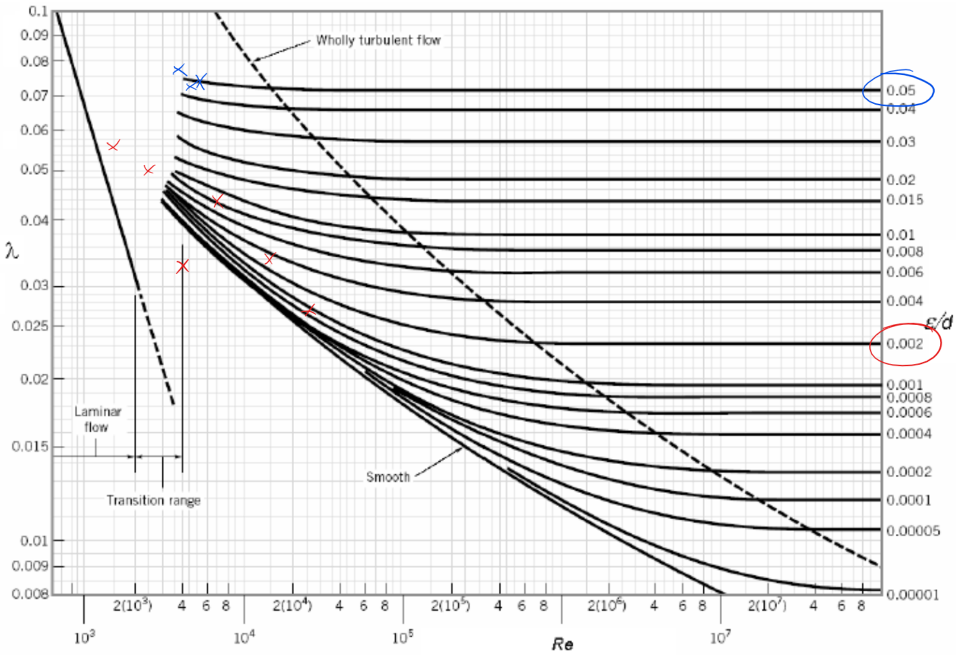

Figure 4: Moody Diagram with the points plotted from the data obtained from the experiment. The red points show the results for the smooth pipe and the blue points show the rough pipe. From this graph we can assume two values for the relative roughness for both the smooth and rough pipe. For the rough pipe, $\frac{\varepsilon}{D} \approx 0.05$ and for the smooth pipe, $\frac{\varepsilon}{D} \approx 0.002$.

[4]

3.2 Pipe bends

Starting with the two tables, Table 3 and 4, they both display the results of the head loss and flow rate, and the loss factor associated with the two aforementioned values.

Table 3: 90° Long Radius Raw Data

Volume (ml)	Time (s)	Volumetric Flow Rate (cm^3/s)	h_1(mm)	h_2 (mm)	Head Loss (mm)	Loss factor, K_l
280	12.52	22.36	351	351	0	0
705	13	54.23	339	339	0	0
800	12.07	66.28	343	342	1	0.2301
895	9.77	91.61	350	345	5	0.6023
1000	10.76	92.94	377	354	23	2.692
2000	10.11	197.8	415	372	43	1.111
4000	14.63	273.4	474	397	77	1.041
4000	10.65	375.6	550	426	124	0.8885

Table 4: 90° Mitre Elbow Raw Data

Volume (ml)	Time (s)	Volumetric Flow Rate (cm^3/s)	h_1(mm)	h_2 (mm)	Head Loss (mm)	Loss factor, K_l
380	15.04	25.27	351	350	1	1.583
550	12.54	43.86	339	334	5	2.627
630	12.11	52.02	340	334	6	2.241
785	11.4	68.86	343	333	10	2.132
955	11.31	84.44	347	332	15	2.127
1000	11.74	85.18	359	328	31	4.319
2000	11.58	172.7	400	315	85	2.880
5000	13.34	374.8	517	264	253	1.820

The graph below in Figure 5 shows the relationship between the loss factor and the flow rate. It is clear to see what effect the two different types of bend have on the loss factor as the flow rate is increased.

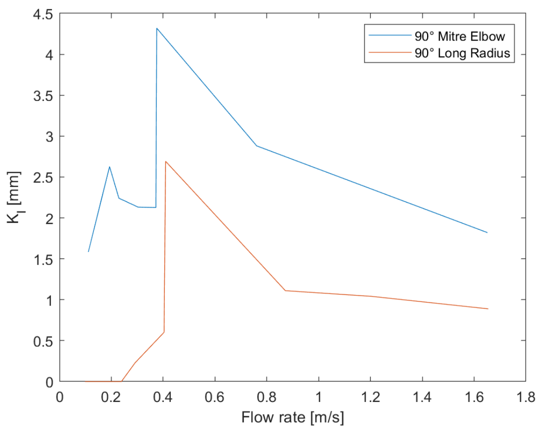

Figure 5: shows a graph of the flow rate against the Loss factor for each of the two different bends in the pipe

4 Discussion

4.1 Major Losses

In the major losses experiment we predicted that as the flow rate is increased the energy losses will also increase. This was because as flow rate increases Reynolds number increases, meaning that the flow is becoming more turbulent and so more energy will be lost in the turbulent flow compared to laminar. From Figure 2 we can see the initial linear region of the graph which correlates to a laminar flow. As the velocity is increased the head loss also increases but by a non linear factor. Therefore, we can see that the flow is transitioning and starting to become more turbulent. The initial linear region of the graph at laminar flow was expected. This is because of Reynolds findings mentioned previously: $h_L \, \alpha \, \bar{U}$ for low Reynolds numbers or laminar flow. Following along the rest of the graph, after the linear region it is still clear that the data follows Reynolds other findings in that for turbulent flow $h_L \, \alpha \, \bar{U}^n$. This can be seen even more clearly in the next graph in Figure 3 when the turbulent region has become now the linear region. From this linear section of the graph n can be found. For the rough pipe n = 2.26 and for the smooth pipe n = 1.77. By then comparing these two values with Figure 2, the two lines of best fit seem to fit with the n values calculated.

Now comparing the results of the two pipes, the rough pipe has a greater head loss than the smooth pipe at any speed. For low velocities the difference is not that high however, the rough pipe still have a slightly higher energy loss. In Figures 2 and 3 both pipes follow similar trends and both are clearly starting from a laminar flow and developing into a turbulent flow. The head loss in a pipe is directly linked to the shear stress at the wall of the pipe [3, Page. 425]. Since the rougher pipe will have had a greater shear stress at the wall the head loss will be greater. What was unexpected between the two pipes is that the smooth pipe seems to develop into a turbulent flow at a lower flow rate than the rough pipe. Naturally it would be expected that the turbulent flow would start at lower speeds for the rough pipe due to all the pipe extrusions on the pipe walls causing for more flow separation. These results rely on only 8 data points which will definitely mean that there are unexplored regions of flow and Reynolds number. Thus the full picture cannot be seen from just these points so going forward, using more data points would be a solution for this. This would allow us to examine what is happening as the flow rate increases more closely and even show us the point where the flow is in transition from laminar to turbulent.

The final part of the major losses experiment was using the results to find that surface roughness inside both of the pipes. By plotting the friction factors and Reynolds numbers in Tables 1 and 2 on the moody diagram, as shown in Figure 4, the relative roughness can be found. Looking at Figure 4 the red points show the smooth pipe and the blue show the rough pipe. By examining the correlation between the points an assumption of the relative roughness can be made. With few points it is difficult to determine the relative roughness. This was especially pro dominant in the rough pipe with only two data points to plot it was very difficult to find a correlation. To fix this more data points in the beginning could be taken, i.e. find the head loss at more flow rates. For the smooth pipe it was slightly simpler to find the relative roughness as there were more points to plot on the moody diagram. These however pose there own challenges. There is a large error between some of the points meaning that the final assumption might be fractionally off.

4.2 Minor Losses

Conclusions from the graph: Starting with Figure 5 there doesn't appear to be any particular relationship between the two and with the few data points attained it is difficult to comment for certain on what the relationship may or may not be. From the graph we can assume that with increasing flow velocity the loss factor increases and hence so does the head loss. Then at a specific value the loss factor reaches a maximum value and then begins to decrease. Looking at the graph, they both follow a similar pattern at around 0.4 m/s there is a large increase in the loss factor and then a similar rate of decrease.

Comparing the results together for both of the pipe bends they follow a very similar shape as the flow rate is increased. There is a large increase starting at around 0.4 m/s which happens in both graphs. The mitre bend has a maximum loss factor of 4.319 and the long radius bend has a much smaller maximum loss factor of 2.692. After the spike there is a decrease once again in both of the pipe bends. The main difference between the two graphs is that at every point the loss factor for the mitre elbow is higher at every point. The graph for the mitre elbow could be described as an almost perfect translation of the long radius bend in the y axis.

Looking at Tables 3 and 4, as flow rate increases so does head loss as expected. Since as flow rate increases the Reynold number increases which can be seen from Table 1 as this pipe was also used for both of the major losses experiments. Reynolds number is increasing which physically means that the flow in the pipe is becoming more turbulent therefore an increase in head loss is expected. There are also energy losses duw to the change in pressure as the flow is forced to change direction. To allow the fluid to flow around the bend there is a force acting inwards onto the fluid causing an increase in pressure towards the outer wall of the pipe and simultaneously a decrease in pressure on the inner wall. This means that the flow feels an adverse pressure gradient and in order to overcome it, more energy must be spent [2, Pages. 266-7]. Also as the flow goes round a corner there is an imbalance between the centripetal forces which causes a swirling secondary flow where more energy is lost [3, Page. 436]. Next the loss factor K_L increases initially to a maximum and then decreases afterwards. This trend is followed in both of the two pipe bends. This was expected because the loss factor is both a dependent on the geometry of the pipe but also on the Reynolds number in the pipe, in other words the type of flow through the pipe. Therefore, there is an increase in the loss factor with an increases in fluid velocity as there is an increase in Reynolds number. At around 0.4m/s flow velocity, Reynolds number is large enough so we can assume that the flow is dominated in majority by inertial forces and so viscous forces are less important. At this point the loss factor is independent from Reynolds number, which can be seen if the graph where it starts to decrease with an increase in Reynolds number. [3, Page. 431]

4.3 Errors

Taking more data points will certainly fix a lot of the errors and it would allow us to see a much clearer vision of how the head loss changes with . The difficulty in this though is the fact that we cannot choose the flow rate very accurately before starting each reading. The dial used to control the flow rate was very sensitive and there was also a delay between turning the dial and the flow rate change becoming visible, therefore calibration was quite difficult. Another issue is that when taking the volume we used a measuring cylinder and a stop watch, both used and read by us which will introduce a human error into the system meaning that the flow rate slightly differs from the actual flow rate. To improve this a hydraulic bench with a flow rate measurer would be ideal in order to take more data points and reduce the human error as much as possible.
Another way to improve this experiment and remove some of the human error is to use more accurate equipment. For example the measuring cylinders resolution not very high, which leaves the recorded value even more so in the users hand. So by using a more accurate measuring cylinder a more accurate volume could have been obtained. Similarly on the hydraulic bench for the high flow rates, the step measurements were in litres making it very difficult to judge the volume at these higher flow rates.

5 Conclusion

In conclusion the major loss in the rough pipe as expected produced a greater energy loss in the system compared to the minor losses. The rough pipe reached a head loss of 689mm over 3 times larger than in the smooth pipe. This was as expected from the beginning as the flow is more turbulent in the rough pipe. Also, there was a higher shear stress resisting the flow in the rough pipe which lead to a greater head loss in this pipe.
With reference to minor losses the mitre elbow produced a greater energy loss than the long radius bend. This was due to the greater change in pressure in the mitre bend, which led to a greater amount of energy used to overcome the opposing pressure gradient. Both of the bends followed a similar trend with K_L, increasing to a maximum and then decreasing again.
In every test, as the flow rate of the water was increased the head loss also increased. This agrees with Reynolds findings mentioned in the beginning and the two relationships that he found are applicable to this experiment.
Finally, the best way to improve this experiment would be to use a more accurate way of finding the flow rate. This would allow us to choose which flow rates specifically to look at, allow us to choose a particular interval between the flow rates such as 0.5m/s to give a comprehensive view of what is happening in the pipe.

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