University of Cincinnati
College of Engineering and Applied Science
Department of Mechanical & Materials Engineering

Course Code : **MECH-5072C**
Course Title : **EXPERIMENTAL METHODS/ME**

Experiment Number : #2
Experiment Title : **Pipe Flow Head loss**

Date(s) Performed : **Feb 10, 2023**
Date Submitted : **Feb 17, 2023**

Group Code : **F-01**

Group Members : **YI, Hongrui: Part A : Major Losses Objective 1 & 2, 2 hours**
: **LIU, Xinran: Part B : Minor Losses Objective 1 & 2, 2 hours**
YANG, Rui: Major Losses Objective 3& 4, 2 hours
YOU, Xuzhen: Part B : Minor Losses Objective 3, 2 hours

Instructor : **Dr. Sarath Kannan**

Table of Contents

1. Objectives

At the end of this experiment, the students are expected to:

(1) Investigate the variation of head loss due to friction with flowrate in the flow of water through a pipe.
(2) Determine the experimental friction factor f.
(3) To calculate theoretical f (for circular pipes), use Re value to determine which formula to use.
(4) Analyze the friction factor for different flow regimes : laminar and turbulent.
(5) Determine the head loss due to the bends/area change for 7 different fittings. (Gate valve, mitre, elbow, short bend, expansion, long bend, contraction)
(6) Determine the loss coefficient k.
(7) Find out if the coefficient is constant or related to flow rate for each type of fitting.

2. Theoretical Background

Calculate flowrate as:

$$\dot{V} = \frac{Volume\ filled}{60s} \tag{1}$$

The velocity v can be calculated using the equation:

$$\dot{V} = Av \tag{2}$$

Where A is the area calculated by using $A = \frac{\pi D^2}{4}$

The Reynolds Number could be calculated as:

$$\mathrm{Re} = \frac{\rho v D}{\mu} \tag{3}$$

Use Darcy Weisbach equation to find the friction factor f:

$$\mathrm{f} = \frac{\Delta H \cdot D \cdot 2g}{L \cdot v^2} \tag{4}$$

To calculate theoretical f (for circular pipes), use Re value to determine which formula to use:

As for $Re < 2300$, Laminar Flow:

$$\mathrm{f} = \frac{64}{\mathrm{Re}} \tag{5}$$

As for $Re > 2300$, Transition Flow:

$$\mathrm{f} = 0.316\mathrm{Re}^{-0.25} \tag{6}$$

For expansion and contraction, calculate the inlet and outlet velocities using the inlet and outlet areas.

$$v_{inlet} = \frac{\text{Flowrate}}{inlet\ area} \tag{7}$$

$$v_{outlet} = \frac{\text{Flowrate}}{outlet\ area} \tag{8}$$

Calculate the loss coefficient k, from the equation:

$$\Delta H = k\frac{v^2}{2g} \tag{9}$$

ΔH is the tested measurement from manometer ended in meters of H_2O;
g is the acceleration for gravity which is taken as $9.8m^2/s$;
v is the velocity.
For expansion and contraction, the total head loss and loss coefficient is calculated by:

$$\Delta H_{total} = \Delta H_{manometer} + (\frac{v_{inlet}^2 - v_{outlet}^2}{2g}) \tag{10}$$

$$k = \frac{\Delta H_{total} \times 2 \times g}{v_{max}^2} \tag{11}$$

where v_{max} is the greater of the two velocities.

Calculate the dynamic head:

$$k = \frac{v_{max}^2}{g} \tag{12}$$

3. Sample Calculation

3.1 Major Losses

3.1.1 Head loss vs Velocity

For both laminar flow and turbulent flow, the methods to calculate experimental friction factor f are the same. In the following, recorded data of Set 1 is used as sample calculation.

Head Loss is:

$$\mathrm{\Delta H = H_1 - H_2 = (158 - 128)\ mm = 3\ mm = 0.03\ m}$$

The volume flowrate in the pipe is:

$$\dot{\mathrm{V}} = \frac{\mathrm{Volume}}{\mathrm{60\ seconds}} = \frac{\mathrm{68\ mL}}{\mathrm{60\ s}} = 1.133\ \mathrm{cm^3/s} = 1.133 \times 10^{-6}\ \mathrm{m^3/s}$$

The cross area of the pipe is:

$$\mathrm{A} = \frac{\pi \mathrm{D}^2}{4} = \frac{\pi \times 0.003^2}{4} = 7.0686 \times 10^{-6}\ \mathrm{m^2}$$

Then the flow velocity can be calculated as:

$$\mathrm{v} = \frac{\dot{\mathrm{V}}}{\mathrm{A}} = \frac{1.133 \times 10^{-6}}{7.0686 \times 10^{-6}} = 0.1603\ \mathrm{m/s}$$

The other 7 sets of data are calculated using MATLAB and the results are shown in result part.

3.1.2 Experimental Friction Factor

At 25 °C, the density of the water is 997 kg/m^3, and the dynamic viscosity is 0.891×10^{-3} Pa·s.

The Reynolds Number under this condition is shown as:

$$\mathrm{Re} = \frac{\rho \mathrm{vD}}{\mu} = \frac{997 \times 0.18038 \times 0.003}{0.891 \times 10^{-3}} = 605.518$$

Use Darcy Weisbach equation to find the friction factor f:

$$\mathrm{f} = \frac{\Delta \mathrm{H} \cdot \mathrm{D} \cdot 2\mathrm{g}}{\mathrm{L} \cdot \mathrm{v}^2} = \frac{0.03 \times 0.003 \times 2 \times 9.81}{0.5 \times 0.1603^2} = 0.1374$$

The other 7 sets of data are calculated using MATLAB and the results are shown in result part.

3.1.3 Theoretical Fiction Factor

When Re is smaller than 2300, take the first data set as example and the theoretical friction factor f will be:

$$\mathrm{f} = \frac{64}{\mathrm{Re}} = \frac{64}{538.2} = 0.1189$$

When Re is larger than 2300, take the fifth data set the theoretical friction factor f will be:

$$f = 0.316\mathrm{Re}^{-0.25} = 0.316 * 2501.2^{-0.25} = 0.0447$$

3.1.4 Friction Factor for Different Flow Regimes

Choose experimental f and Re for all Re > 2300. Then,

$$f = k\mathrm{Re}^{n}$$

k and n need to be determined.

Taking the natural logarithm of both sides to find k and n,

$$\ln\left(f_{exp}\right) = \ln(k) + n\ln(\mathrm{Re})$$

Plot ln(Re) on the x-axis and ln(f) on the y-axis. You will get a downward sloping straight line. Obtain the equation of the line as $y = mx + c$ and then determine the value of n and k as:

$$n = m$$

$$k = e^{c}$$

3.2 Minor Losses

3.2.1 Head Losses Due to the Bends/Area Change

To Calculate the flowrate, use the following equation:

$$\dot{V} = \frac{Volume\ filled}{60s}$$

Table 1. Minor Head Loss Data sheet

SET 1	Col = 10mL	Time = 60s					
Fitting	CONT	LONG	EXPA	SHORT	ELBOW	MITRE(set)	GATE
Manometer h1 (m)	0.195	0.192	x	0.172	0.156	0.113	Gauge reading (bar)
Manometer h2 (m)	0.177	0.189	x	0.165	0.131	0.081	
Δh (m)	0.018	0.003	-0.007	0.007	0.025	0.032	1.2
SET 2	Col = 12mL	Time = 60s					
Fitting	CONT	LONG	EXPA	SHORT	ELBOW	MITRE(set)	GATE
Manometer h1 (m)	0.266	0.266	xx	0.243	0.213	0.153	Gauge reading (bar)
Manometer h2 (m)	0.243	0.26	xx	0.227	0.182	0.105	
Δh (m)	0.023	0.006	-0.015	0.016	0.031	0.048	1.6
SET 3	Col = 17mL	Time = 60s					
Fitting	CONT	LONG	EXPA	SHORT	ELBOW	MITRE(set)	GATE
Manometer h1 (m)	0.437	0.436	xx	0.393	0.338	0.233	Gauge reading (bar)
Manometer h2 (m)	0.393	0.424	xx	0.361	0.28	0.145	
Δh (m)	0.044	0.012	-0.016	0.032	0.058	0.088	1.9
SET 4	Col = 18mL	Time = 60s					
Fitting	CONT	LONG	EXPA	SHORT	ELBOW	MITRE(set)	GATE
Manometer h1 (m)	0.373	0.375	xx	0.32	0.254	0.128	Gauge reading (bar)
Manometer h2 (m)	0.319	0.358	xx	0.282	0.182	0.021	
Δh (m)	0.054	0.017	-0.019	0.038	0.072	0.107	2

According to data taken in the lab, take set 1 for a sample calculation as follows:

$$\dot{V}_1 = \frac{Volume\ filled}{60s} = \frac{10L}{60s} = 1.67 \times 10^{-4}\ m^3/s$$

The velocity v can be calculated using the equation:

$$\dot{V} = Av$$

A is the area calculated by using $A = \frac{\pi D^2}{4}$, and D is 0.0183m.

So, the velocity of set 1 is:

$$v = \frac{1.67 \times 10^{-4}\ m^3/s}{\pi \times 0.0183^2/4\ m^2} = 6.34 \times 10^{-1}\ m/s$$

For expansion and contraction, the inlet and outlet velocities should be using the area of the inlet and outlet. The following calculation can be made:

Calculate the expansion inlet velocity:

$$v_{inlet} = \frac{\dot{V}_1}{inlet\ area} = \frac{1.67 \times 10^{-4}\ m^3/s}{2.63 \times 10^{-4}\ \ m^2} = 6.34 \times 10^{-1}\ m/s$$

Calculate the expansion outlet velocity:

$$v_{outlet} = \frac{\dot{V}_1}{outlet\ area} = \frac{1.67 \times 10^{-4}\ m^3/s}{4.52 \times 10^{-4}\ \ m^2} = 3.68 \times 10^{-1}\ m/s$$

Calculate the contraction inlet velocity:

$$v_{inlet} = \frac{\dot{V}_1}{inlet\ area} = \frac{1.67 \times 10^{-4}\ m^3/s}{4.52 \times 10^{-4}\ \ m^2} = 3.68 \times 10^{-1}\ m/s$$

Calculate the contraction outlet velocity:

$$v_{outlet} = \frac{\dot{V}_1}{outlet\ area} = \frac{1.67 \times 10^{-4}\ m^3/s}{2.63 \times 10^{-4}\ \ m^2} = 6.34 \times 10^{-1}\ m/s$$

3.2.2 Minor Losses: Loss Coefficient

Calculate the loss coefficient k, from the equation:

$$\Delta H = k\frac{v^2}{2g}$$

ΔH is the tested measurement from manometer ended in meters of H_2O;
g is the acceleration for gravity which is taken as $9.8m^2/s$;
v is the velocity.
Take the set 1 for Gate Valve as an example for calculation:

$$\Delta H = 1.2\ bar = \ \ 12.24\ m\ of\ H_2O$$

$$k = \frac{\Delta H \times 2 \times g}{v^2} = \frac{12.24 \times 2 \times 9.8}{(6.34 \times 10^{-1})^2} = 597$$

For expansion and contraction, the total head loss and loss coefficient is calculated by:

$$\Delta H_{total} = \Delta H_{manometer} + (\frac{v_{inlet}^2 - v_{outlet}^2}{2g})$$

$$k = \frac{\Delta H_{total} \times 2 \times g}{v_{max}^2}$$

$$Dynamic\ head = \frac{v_{max}^2}{g}$$

Where v_{max} is the greater one of the v_{inlet} and v_{outlet}.
Use the set 1 for Expansion for sample calculation:

$$\Delta H_{total} = -0.007 + \left(\frac{(6.34 \times 10^{-1})^2 - (3.68 \times 10^{-1})^2}{2 \times 9.8}\right)m = \ 6.56\text{E} \times 10^{-3}\ m\ of\ H_2O$$

$$k = \frac{2.06 \times 10^{-2} \times 2 \times 9.8}{(6.34 \times 10^{-1})^2} = 0.32$$

$$Dynamic\ head = \frac{(6.34 \times 10^{-1})^2}{9.8} = \ 2.05 \times 10^{-2}\ m\ of\ H_2O$$

4. Result

4.1 Major Losses

4.1.1 Head loss vs Velocity

Table 2. Head loss, Flowrate, Flow Velocity

Set	Head Loss ΔH (mm H_2O)	Flow Rate $\dot{V}$ (m^3/s)	Flow Velocity V (m/s)
1	30	1.133×10^{-6}	0.1603
2	48	2.633×10^{-6}	0.3725
3	81	3.433×10^{-6}	0.4857
4	153	4.667×10^{-6}	0.6602
5	199	5.267×10^{-6}	0.7451
6	249	5.900×10^{-6}	0.88347
7	300	6.800×10^{-6}	0.9620
8	400	7.500×10^{-6}	1.0610

Note:
Set 1~4 are laminar flows, whose Reynolds Numbers are smaller than 2300.
Set 5~8 are turbulent flows, whose Reynolds Numbers are larger than 2300.

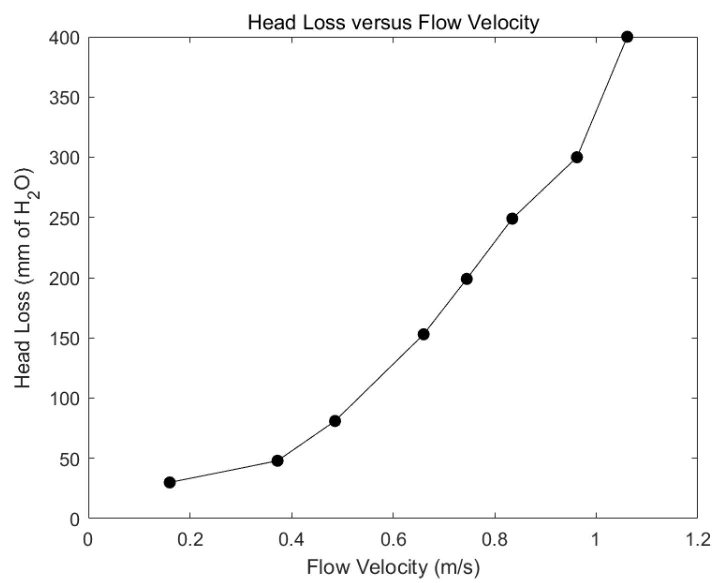

Figure 1. Relation between Head Loss and Flow Velocity

4.1.2 Experimental Friction Factor

Table 2. Head loss, Flowrate, Flow Velocity, Re, Experimental f

Set	Head Loss ΔH (mm H_2O)	Re	Experimental Friction Factor
1	30	538.2	0.1374
2	48	1250.6	0.0407
3	81	1630.5	0.0404
4	153	2216.2	0.0413
5	199	2501.2	0.0422
6	249	2801.9	0.0421
7	300	3229.4	0.0382
8	400	3561.8	0.0418

Note:
Set 1~4 are laminar flows, whose Reynolds Numbers are smaller than 2300.
Set 5~8 are turbulent flows, whose Reynolds Numbers are larger than 2300.

4.1.3 Theoretical Fiction Factor

Table 3. Theoretical f and Error

Theoretical Friction Factor	Error
0.118914902	15.54%
0.051175436	20.47%
0.039251763	2.93%
0.02887826	43.01%
0.044683787	5.56%
0.04343341	3.07%
0.041918586	8.87%
0.040904369	2.19%

4.1.4 Friction Factor for Different Flow Regimes

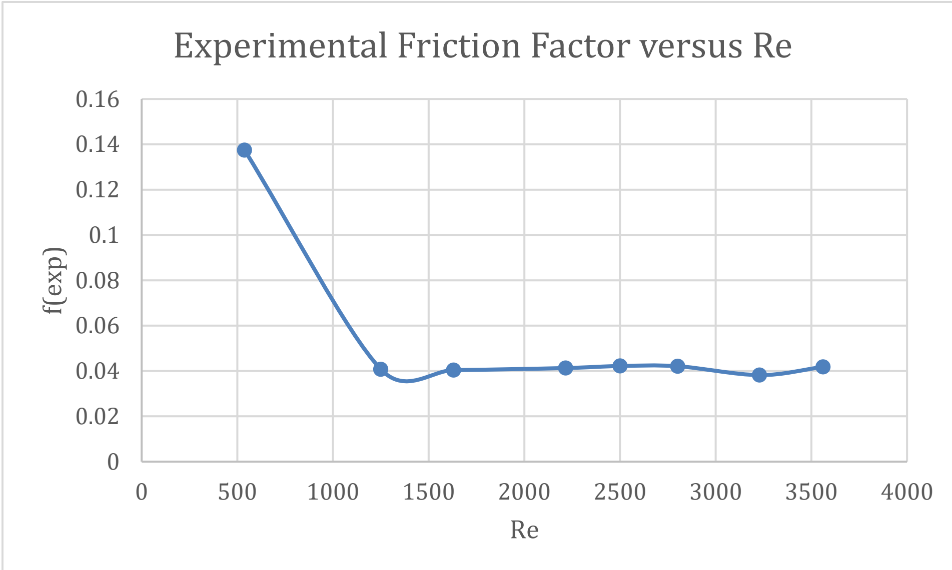

Figure 2. Experimental Friction Factor versus Re

Table 4. Experimental Curve Fit data for Turbulent Flow

Turbulent Flow Set	Re	Experimental Friction Factor	Experimental Curve Fit	
			$\ln(f)$	$\ln(Re)$
5	2501.2	0.0422	3.165335058	7.824525896
6	2801.9	0.0421	3.167707538	7.938053037
7	3229.4	0.0382	3.264919763	8.08005164
8	3561.8	0.0418	3.174858939	8.178021314

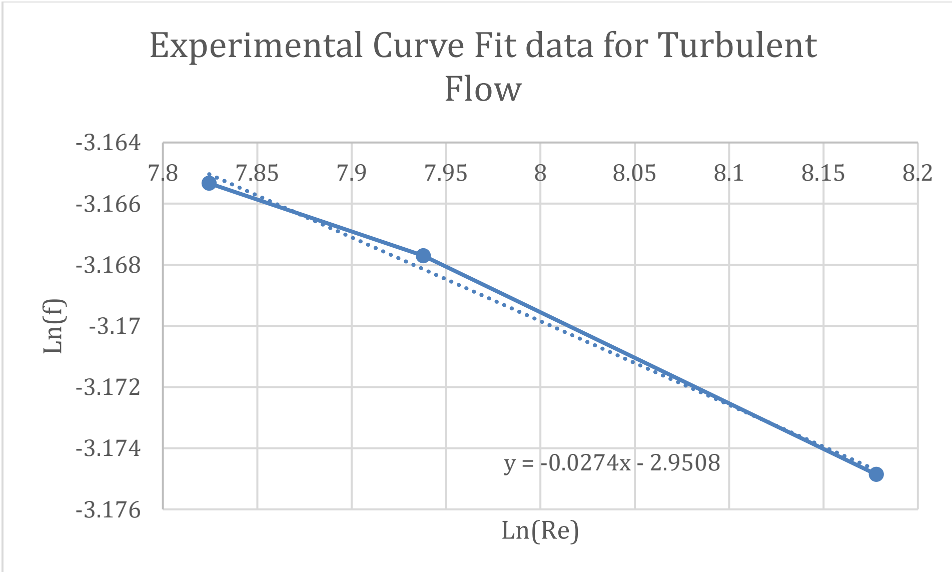

Figure 3. Curve fit for turbulent data and equation

The data of the seventh group has obvious errors, so the data of the 5th, 6th and 8th groups are used for fitting .

$$\mathbf{y = mx + c}$$

$n = m$=-0.0274

$k = e^{c} = e^{-2.9508} = 0.052$

4.2 Minor Losses

<u>4.2.1 Head Losses Due to the Bends/Area Change & Loss Coefficient</u>

Table 5. Loss coefficient and dynamic head tabulation for gate valve, mitre, elbow, short bend and long bend

Gate valve						
Set	ΔH (bar)	ΔH (m inH2O)	Flowrate (m3/s)	Velocity(m/s)	Loss Coefficient	Dynamic head
1	1.2	12.24	1.67E-04	6.34E-01	5.97E+02	2.05E-02
2	1.6	16.32	2.00E-04	7.60E-01	5.53E+02	2.95E-02
3	1.9	19.38	2.83E-04	1.08E+00	3.27E+02	5.92E-02
4	2	20.39	3.00E-04	1.14E+00	3.07E+02	6.64E-02
Mitre						
Set	ΔH (mm in H2O)	ΔH (m inH2O)	Flowrate (m3/s)	Velocity(m/s)	Loss Coefficient	Dynamic head
1	32	0.032	1.67E-04	6.34E-01	1.56E+00	2.05E-02
2	48	0.048	2.00E-04	7.60E-01	1.63E+00	2.95E-02
3	88	0.088	2.83E-04	1.08E+00	1.49E+00	5.92E-02
4	107	0.107	3.00E-04	1.14E+00	1.61E+00	6.64E-02
Long						
Set	ΔH (mm in H2O)	ΔH (m inH2O)	Flowrate (m3/s)	Velocity(m/s)	Loss Coefficient	Dynamic head
1	3	0.003	1.67E-04	6.34E-01	1.46E-01	2.05E-02
2	6	0.006	2.00E-04	7.60E-01	2.03E-01	2.95E-02
3	12	0.012	2.83E-04	1.08E+00	2.03E-01	5.92E-02
4	17	0.017	3.00E-04	1.14E+00	2.56E-01	6.64E-02
Short						
Set	ΔH (mm in H2O)	ΔH (m inH2O)	Flowrate (m3/s)	Velocity(m/s)	Loss Coefficient	Dynamic head
1	7	0.007	1.67E-04	6.34E-01	3.42E-01	2.05E-02
2	16	0.016	2.00E-04	7.60E-01	5.42E-01	2.95E-02
3	32	0.032	2.83E-04	1.08E+00	5.40E-01	5.92E-02
4	38	0.038	3.00E-04	1.14E+00	5.73E-01	6.64E-02
Elbow						
Set	ΔH (mm in H2O)	ΔH (m inH2O)	Flowrate (m3/s)	Velocity(m/s)	Loss Coefficient	Dynamic head
1	25	0.025	1.67E-04	6.34E-01	1.22E+00	2.05E-02
2	31	0.031	2.00E-04	7.60E-01	1.05E+00	2.95E-02
3	58	0.058	2.83E-04	1.08E+00	9.80E-01	5.92E-02
4	72	0.072	3.00E-04	1.14E+00	1.08E+00	6.64E-02

Table 6. Loss coefficient and dynamic head tabulation for expansion and contraction

Expansion v(inlet) > v(outlet)								
ΔH (mm inH2O)	ΔH (m inH2O)	Flowrate (m3/s)	Inlet velocity (m/s)	Outlet velocity (m/s)	Deceleration head	Total head loss	Loss coefficient	Dynamic head
-7	-0.007	1.67E-04	6.34E-01	3.68E-01	1.36E-02	6.56E-03	3.20E-01	2.05E-02
-15	-0.015	2.00E-04	7.60E-01	4.42E-01	1.95E-02	4.53E-03	1.53E-01	2.95E-02
-16	-0.016	2.83E-04	1.08E+00	6.26E-01	3.92E-02	2.32E-02	3.92E-01	5.92E-02
-19	-0.019	3.00E-04	1.14E+00	6.63E-01	4.39E-02	2.49E-02	3.76E-01	6.64E-02
Contraction v(inlet) < v(outlet)								
ΔH (mm inH2O)	ΔH (m inH2O)	Flowrate (m3/s)	Inlet velocity (m/s)	Outlet velocity (m/s)	Deceleration head	Total head loss	Loss coefficient	Dynamic head
18	0.018	1.67E-04	3.68E-01	6.34E-01	-1.36E-02	4.44E-03	2.17E-01	2.05E-02
23	0.023	2.00E-04	4.42E-01	7.60E-01	-1.95E-02	3.47E-03	1.18E-01	2.95E-02
44	0.044	2.83E-04	6.26E-01	1.08E+00	-3.92E-02	4.81E-03	8.12E-02	5.92E-02
54	0.054	3.00E-04	6.63E-01	1.14E+00	-4.39E-02	1.01E-02	1.52E-01	6.64E-02

4.2.2 Loss Coefficient vs Flow Rate

With the result in Table and Table , coding in matlab as Figure demonstrated that Head loss $\alpha \ \frac{v^2}{2g}$ which is the dynamic head.

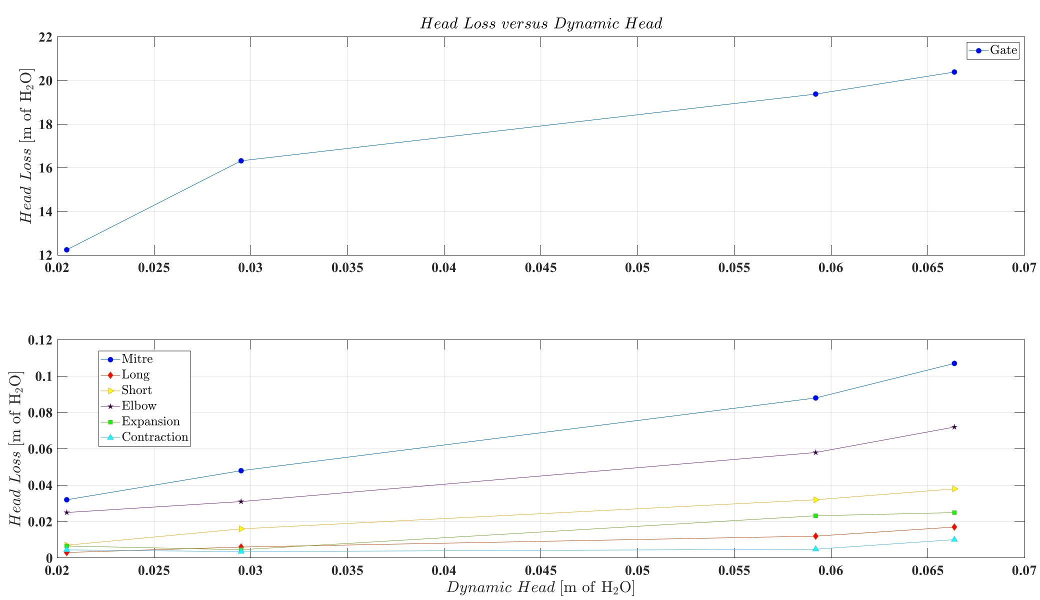

Figure 4. Head Loss versus Dynamic Head

With the result in Table and Table , coding in matlab as Figure demonstrated that the Loss Coefficient k is nearly constant with flowrate.

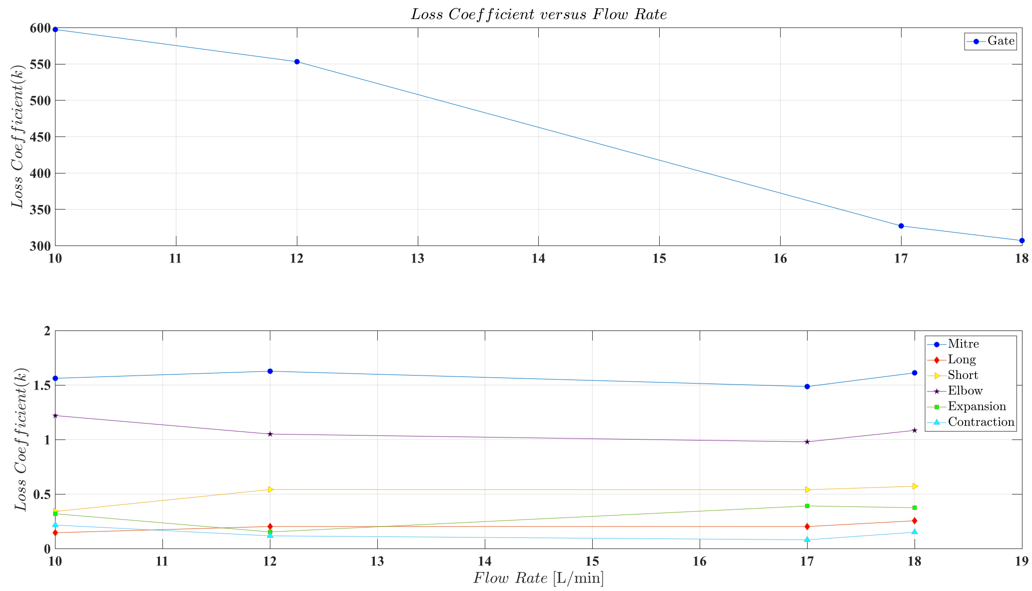

Figure 5. Loss Coefficient versus Flow Rate

5. Discussion and Conclusions

5.1. Major loss

(1) f vs Re

How does the friction factor f vary with the Reynolds number, Re? Discuss with respect to the laminar and turbulent regime. Why is this so?

As for laminar flow, the friction factor decreases while the Reynolds number increasing.

As for turbulent flow, the friction factor decreases while the Reynolds number increasing. However, the magnitude of the change in turbulent flow is really small, which means that the friction factor versus Reynolds Number curve tends to be flat in turbulent region.

Friction factor depends on the flow near the wall, which is called the laminar sub-layer or viscous sub-layer. Due to the presence of surface roughness, this layer is present near the wall where viscous forces dominate, creating high shear stress to suppress turbulence.

When the Reynolds Number increases, the kinetic energy of the fluid increases. In this case, kinetic forces dominate viscous forces, and the thickness of the sub-layer decreases. Hence, friction factor decreases with increasing Reynolds Number.

What's more, even in a perfectly smooth pipe, there is microscopic roughness which creates this viscous sub-layer. Therefore, as the Reynolds Number becomes higher, friction factor gradually becomes a constant varying only with surface roughness rather than decreases to zero.

(2) ΔH vs v (or flowrate)

How does the head loss (pressure drop) vary with flowrate or flow velocity? Discuss with respect to the laminar and turbulent regimes.

Theoretically, ΔH is proportional to velocity for laminar flow, but ΔH is proportional to velocity squared for turbulent flow. Why is this so?

Does the experimental data show this trend? (Observe the slope of the ΔH vs flowrate curve in the laminar and turbulent ranges of the flowrate)

According to the result shown in Figure, the head loss in the tube is proportional to the flow velocity. Namely, as the flow velocity increases, the pressure drops in the tube increases. Also, from the relationship curve, both laminar flows (data point 1~4 on the curve) and turbulent flows (data point 5~8) have a nearly linear relationship of the head loss and flow velocity. However, the increase rate of laminar flows is smaller than the increase rate of the turbulent flows. This indicates that the head loss of turbulent flows is more sensitive to flow velocity than laminar flows.

Theoretically, based on the Darcy Weisbach Equation on pressure loss/head loss, the loss in a pipe is proportional to the friction factor and the velocity square of the flow. For laminar flow, the friction factor is inversely proportional to Reynolds number of the flow. Since Reynolds number is proportional to the velocity of the flow, the head loss of laminar flow is proportional to flow velocity square and inversely proportional to flow velocity. As a result, laminar flow head loss only proportional to 1 order of the flow velocity. For turbulent flow, the friction factor is independent with Reynolds number, thus it is independent with the flow velocity. Hence, the head loss for turbulent flow in a pipe is proportional to the flow velocity square by Darcy Weisbach Equation.

In the experiment, for laminar flows, the four data points does not form a perfect linear curve. This is due to the random errors. For example, in the measurement of flow velocity, there may be small water volume retained on the inner surface of the container, causing a deviation to the actual volume. However, the average slope value of laminar flows is much smaller than the slope of turbulent flow data. This checks the trend of the theoretical relationship that discussed above.

(3) Compare the experimental f with the theoretical f. What is the maximum % difference compared to the theoretical f?

According to Tables 2 and 3, the percentage differences between the experimental and theoretical friction coefficients for the eight data sets are mostly below 10%. However, the largest percentage difference occurs in laminar flow at a Reynolds number of 2216.2, about 43%. This huge difference is justified. Because the Reynolds number of the flow is close to about 2300, it is in the flow transition zone. According to Moody's charts, there is no exact relationship between Reynolds, roughness, and coefficient of friction in the transition zone. The behavior of this flow is therefore experimentally unpredictable, which is the reason for the large percentage difference compared to the theoretical coefficient of friction.

5.2. Minor loss

(1) K vs flowrate

Does loss coefficient vary with flowrate? Why is this so?

Order the fittings according to the loss coefficient k, from highest to lowest. How many times larger is k for gate valve compared to all fittings?

Loss coefficient does not vary with flowrate. It can be seen from the Figure , loss coefficient is nearly constant with flowrate. This is because minor loss is caused by secondary flows induced by curvature or recirculation. Loss coefficient k is affected by geometry, proximity of other fittings.

Order for all fittings according to the loss coefficient from highest to lowest is: Gate valve, Mitre, Elbow, Short bend, Expansion, Long bend, Contraction. Compared to all fittings, the loss coefficient for gate valve is about 200 to 2000 times larger than other fittings.

(2) ΔH vs $v^2/2g$

How does head loss ΔH vary with dynamic head, which is a measure of the kinetic energy of the flowing water? Why is this so?

As dynamic head increasing, the head loss ΔH will increase as Figure shown. Head loss $\alpha\ \frac{v^2}{2g}$ which is the dynamic head.

Dynamic head should be the measure of the kinetic energy of the flowing water. Since $\Delta H = k\,\frac{v^2}{2g}$, where k is the loss coefficient that will vary with the different type of fittings. It will lead to the kinetic energy of the flowing water change with type of fittings if there are more than one type of bend of the flowing water.

APPENDICES

A – MATLAB Code (or Excel, other computational software, etc)

```
Part A
% Lab 2 - Major Loss
% Calculate experimental friction factor
clear;clc
D=0.003;
L=0.5;
Density=997;
g=9.81;
miu=0.891*10^(-3); % Dynamic Viscosity
H1=[158 358 337 414 445 390 432 428]/1000
H2=[128 310 256 261 246 141 132 28]/1000
delta_H=H1-H2
Volume=[68 158 206 280 316 354 408 450]/(10^6)
FlowRate=Volume/60
A=pi*D^2/4
Velocity=FlowRate/A
Re=Density*Velocity*D/miu
f_exp=delta_H*D*2*g./(L*Velocity.^2)

% Calculate theoretical friction factor and error
for n=1:4
    f_th(n)=64/Re(n) % Laminar Flow
end
for n=1:4
    f_th(n+4)=0.316*Re(n+4)^(-0.25) % Turbulent Flow
end
f_error=abs(f_exp-f_th)./f_th*100 % Percent error

% Head loss versus flow velocity
plot(Velocity,delta_H*1000,'-ok','MarkerFaceColor','k')
xlabel('Flow Velocity (m/s)');ylabel('Head Loss (mm of H_2O)')
title('Head Loss versus Flow Velocity')


Part B
%% Lab 2
close all
clear all
clc
set(0,'DefaultAxesFontName', 'Times New Roman')
set(0,'DefaultAxesFontSize', 22)
set(0,'defaultlinelinewidth',0.5)
set(0,'DefaultLineMarkerSize', 8)
set(0,'defaultAxesFontWeight','bold')

%% Code
%% Objective 2.3
data1 = xlsread('Data_Lab2.xlsx','sheet3');
data2 = xlsread('Data_Lab2.xlsx','sheet4');

hl_Gate = data1(2:5,3);
```

```
dh_Gate = data1(2:5,7);
fr_Gate = data1(2:5,4)*60*1000;
k_Gate = data1(2:5,6);

hl_Mitre = data1(8:11,3);
dh_Mitre = data1(8:11,7);
fr_Mitre = data1(8:11,4)*60*1000;
k_Mitre = data1(8:11,6);

hl_Long = data1(14:17,3);
dh_Long = data1(14:17,7);
fr_Long = data1(14:17,4)*60*1000;
k_Long = data1(14:17,6);

hl_Short = data1(20:23,3);
dh_Short = data1(20:23,7);
fr_Short = data1(20:23,4)*60*1000;
k_Short = data1(20:23,6);

hl_Elbow = data1(26:29,3);
dh_Elbow = data1(26:29,7);
fr_Elbow = data1(26:29,4)*60*1000;
k_Elbow = data1(26:29,6);

hl_Expansion = data2(1:4,7);
dh_Expansion = data2(1:4,9);
fr_Expansion = data2(1:4,3)*60*1000;
k_Expansion = data2(1:4,8);

hl_Contraction = data2(7:10,7);
dh_Contraction = data2(7:10,9);
fr_Contraction = data2(7:10,3)*60*1000;
k_Contraction = data2(7:10,8);

% Result
figure
subplot(2,1,1)
plot(dh_Gate,hl_Gate,'o-','MarkerFaceColor','b')
ylabel(['$ Head\ Loss\;\mathrm{[m\ of\ H_2O]} $'],'interpreter','latex')
title(['$ Head\ Loss\ versus\ Dynamic\ Head $'],'interpreter','latex')
legend(['Gate'],'interpreter','latex')
grid on
subplot(2,1,2)
plot(dh_Mitre,hl_Mitre,'o-','MarkerFaceColor','b')
hold on
plot(dh_Long,hl_Long,'d-','MarkerFaceColor','r')
plot(dh_Short,hl_Short,'>-','MarkerFaceColor','y')
plot(dh_Elbow,hl_Elbow,'p-','MarkerFaceColor','k')
plot(dh_Expansion,hl_Expansion,'s-','MarkerFaceColor','g')
plot(dh_Contraction,hl_Contraction,'^-','MarkerFaceColor','c')
ylabel(['$ Head\ Loss\;\mathrm{[m\ of\ H_2O]} $'],'interpreter','latex')
xlabel(['$ Dynamic\ Head\;\mathrm{[m\ of\ H_2O]} $'],'interpreter','latex')
legend(['Mitre'],['Long'],['Short'],['Elbow'],['Expansion'],['Contraction'],'
interpreter','latex')
grid on
```

```
figure
subplot(2,1,1)
plot(fr_Gate,k_Gate,'o-','MarkerFaceColor','b')
ylabel(['$ Loss\ Coefficient(k) $'],'interpreter','latex')
title(['$ Loss\ Coefficient\ versus\ Flow\ Rate $'],'interpreter','latex')
legend(['Gate'],'interpreter','latex')
grid on
subplot(2,1,2)
plot(fr_Mitre,k_Mitre,'o-','MarkerFaceColor','b')
hold on
plot(fr_Long,k_Long,'d-','MarkerFaceColor','r')
plot(fr_Short,k_Short,'>-','MarkerFaceColor','y')
plot(fr_Elbow,k_Elbow,'p-','MarkerFaceColor','k')
plot(fr_Expansion,k_Expansion,'s-','MarkerFaceColor','g')
plot(fr_Contraction,k_Contraction,'^-','MarkerFaceColor','c')
ylabel(['$ Loss\ Coefficient(k) $'],'interpreter','latex')
xlabel(['$ Flow\ Rate\;\mathrm{[L/min]} $'],'interpreter','latex')
legend(['Mitre'],['Long'],['Short'],['Elbow'],['Expansion'],['Contraction'],'
interpreter','latex')
grid on
```

Gate valve									
Set	ΔH (bar)	ΔH (m inH2O)	Flowrate (m3/s)	Velocity(m/s)	Loss Coefficient	Dynamic head		A	0.000263
1	1.2	12.24	1.67E-04	6.34E-01	5.97E+02	2.05E-02			
2	1.6	16.32	2.00E-04	7.60E-01	5.53E+02	2.95E-02			
3	1.9	19.38	2.83E-04	1.08E+00	3.27E+02	5.92E-02			
4	2	20.39	3.00E-04	1.14E+00	3.07E+02	6.64E-02			
Mitre									
Set	ΔH (mm in H2O)	ΔH (m inH2O)	Flowrate (m3/s)	Velocity(m/s)	Loss Coefficient	Dynamic head			
1	32	0.032	1.67E-04	6.34E-01	1.56E+00	2.05E-02			
2	48	0.048	2.00E-04	7.60E-01	1.63E+00	2.95E-02			
3	88	0.088	2.83E-04	1.08E+00	1.49E+00	5.92E-02			
4	107	0.107	3.00E-04	1.14E+00	1.61E+00	6.64E-02			
Long									
Set	ΔH (mm in H2O)	ΔH (m inH2O)	Flowrate (m3/s)	Velocity(m/s)	Loss Coefficient	Dynamic head			
1	3	0.003	1.67E-04	6.34E-01	1.46E-01	2.05E-02			
2	6	0.006	2.00E-04	7.60E-01	2.03E-01	2.95E-02			
3	12	0.012	2.83E-04	1.08E+00	2.03E-01	5.92E-02			
4	17	0.017	3.00E-04	1.14E+00	2.56E-01	6.64E-02			
Short									
Set	ΔH (mm in H2O)	ΔH (m inH2O)	Flowrate (m3/s)	Velocity(m/s)	Loss Coefficient	Dynamic head			
1	7	0.007	1.67E-04	6.34E-01	3.42E-01	2.05E-02			
2	16	0.016	2.00E-04	7.60E-01	5.42E-01	2.95E-02			
3	32	0.032	2.83E-04	1.08E+00	5.40E-01	5.92E-02			
4	38	0.038	3.00E-04	1.14E+00	5.73E-01	6.64E-02			
Elbow									
Set	ΔH (mm in H2O)	ΔH (m inH2O)	Flowrate (m3/s)	Velocity(m/s)	Loss Coefficient	Dynamic head			
1	25	0.025	1.67E-04	6.34E-01	1.22E+00	2.05E-02			
2	31	0.031	2.00E-04	7.60E-01	1.05E+00	2.95E-02			
3	58	0.058	2.83E-04	1.08E+00	9.80E-01	5.92E-02			
4	72	0.072	3.00E-04	1.14E+00	1.08E+00	6.64E-02			

Expansion v(inlet) > v(outlet)

ΔH (mm inH2O)	ΔH (m inH2O)	Flowrate (m3/s)	Inlet velocity (m/s)	Outlet velocity (m/s)	Deceleration head	Total head loss	Loss coefficient	Dynamic head
-7	-0.007	1.67E-04	6.34E-01	3.68E-01	1.36E-02	6.56E-03	3.20E-01	2.05E-02
-15	-0.015	2.00E-04	7.60E-01	4.42E-01	1.95E-02	4.53E-03	1.53E-01	2.95E-02
-16	-0.016	2.83E-04	1.08E+00	6.26E-01	3.92E-02	2.32E-02	3.92E-01	5.92E-02
-19	-0.019	3.00E-04	1.14E+00	6.63E-01	4.39E-02	2.49E-02	3.76E-01	6.64E-02

Contraction v(inlet) < v(outlet)

ΔH (mm inH2O)	ΔH (m inH2O)	Flowrate (m3/s)	Inlet velocity (m/s)	Outlet velocity (m/s)	Deceleration head	Total head loss	Loss coefficient	Dynamic head
18	0.018	1.67E-04	3.68E-01	6.34E-01	-1.36E-02	4.44E-03	2.17E-01	2.05E-02
23	0.023	2.00E-04	4.42E-01	7.60E-01	-1.95E-02	3.47E-03	1.18E-01	2.95E-02
44	0.044	2.83E-04	6.26E-01	1.08E+00	-3.92E-02	4.81E-03	8.12E-02	5.92E-02
54	0.054	3.00E-04	6.63E-01	1.14E+00	-4.39E-02	1.01E-02	1.52E-01	6.64E-02

	Expansion	Contraction
Ain	2.63E-04	4.52E-04
Aout	4.52E-04	2.63E-04

B – Scanned Lab Notes

Data Sheet

Major Head Loss

Set	Volume Collected V (mL)	Time to Collect t (s)	Manometer ΔH (mm)
1	68	60	30 | 158 - 128
2	158	60	48 ~~50~~ | 358 - 310
3	20~~8~~6	60	81 ~~80~~ | 337 - 256
4	280	60	153 ~~150~~ | 414 - 261
5	316	60	199 ~~200~~ | 445 - 246
6	354	60	249 ~~250~~ | 390 - 141
7	408	60	300 | 432 - 132
8	450	60	400 | 428 - 28

Minor Head Loss

SET 1	Vol = 10~~.4~~ L	Time = 60 s					
Fitting	CONT	LONG	EXPA.	SHORT	ELBOW	MITRE(set)	GATE
Manometer h1	195	192	x	172	156	113	Gauge reading
Manometer h2	177	189	x	165	131	81	(bar) ~~1~~.2
Δh	18	3	-7	7	25	32	

SET 2	Vol = 12 L	Time = 60 s					
Fitting	CONT	LONG	EXPA.	SHORT	ELBOW	MITRE(set)	GATE
Manometer h1	266	266	xx	243	213	153	Gauge reading
Manometer h2	243	260	xx	227	182	105	(bar) ~~35~~ 1.6
Δh	23	6	-15	16	31	48	

SET 3	Vol = 17 L	Time = 60 s					
Fitting	CONT	LONG	EXPA.	SHORT	ELBOW	MITRE(set)	GATE
Manometer h1	437	436	xx	393	338	233	Gauge reading
Manometer h2	393	424	xx	361	280	145	(bar) 1.9
Δh	44	12	-16	32	58	88	

SET 4	Vol = 18 L	Time = 60 s					
Fitting	CONT	LONG	EXPA.	SHORT	ELBOW	MITRE(set)	GATE
Manometer h1	373	375	xx	320	254	128	Gauge reading
Manometer h2	319	358	xx	282	182	21	(bar) 2.0
Δh	54	17	-19	38	72	107	

Group Number:

Date: