UNIVERSITY OF THE DISTRICT COLUMBIA

School of Engineering and Applied Sciences

Department of Mechanical Engineering

MECH-322 – Thermo Fluids Lab

11— —18

FLUID FRICTION HEAD LOSSES

INTRODUCTION

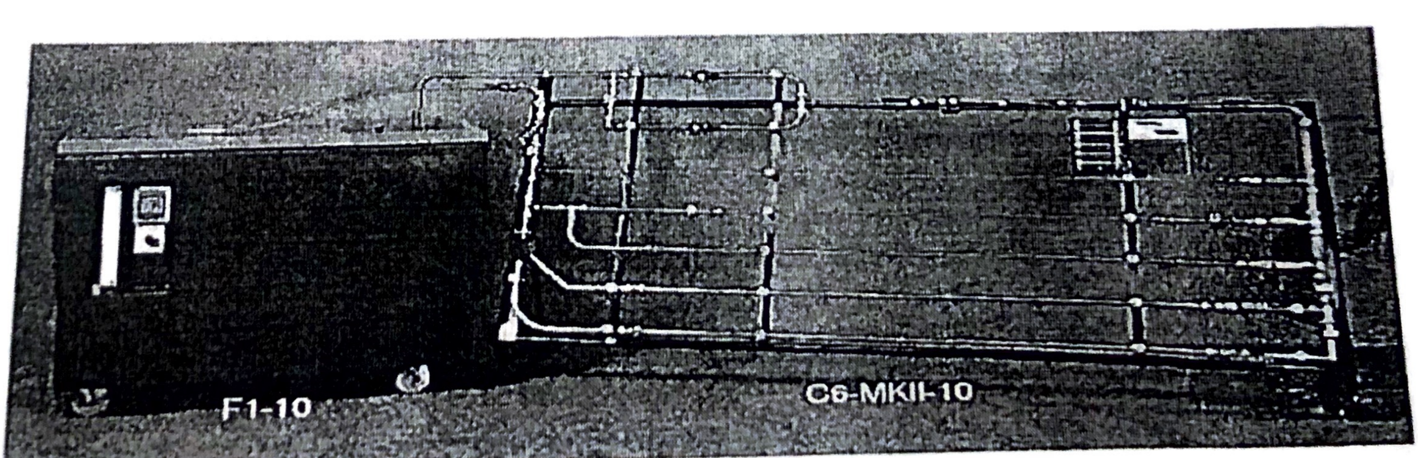
The Armfield C6-MKI 1-10 Fluid Friction Apparatus is designed to allow the detailed study of the fluid friction head losses which occur when an incompressible fluid flows through pipes, bends, valves and pipe flow metering devices.

Friction head losses in straight pipes of different sizes can be investigated over a range of Reynolds' numbers from 10^3 to nearly10^5, thereby covering the laminar, transitional and turbulent flow regimes in smooth pipes. A further test pipe is artificially roughened and, at the higher Reynolds' numbers, shows a clear departure from typical smooth bore pipe characteristics.

In addition to the smooth and roughened pipes, a wide range of pipeline components are fitted, including pipe fittings and control valves, allowing investigation of the losses caused by this type of connection. A clear acrylic section of pipeline houses a Venturi meter, an orifice plate assembly and a Pitot tube, so that these can be investigated as flow measurement devices.

APPARATUS & SUPPLIES

1. The Armfield C6-MKI 1-10 Fluid Friction Apparatus.
2. The Armfield F1-10 Hydraulics Bench.
3. The Extech Differential Pressure Manometer.
4. A Stop Watch.



Equipment Diagrams

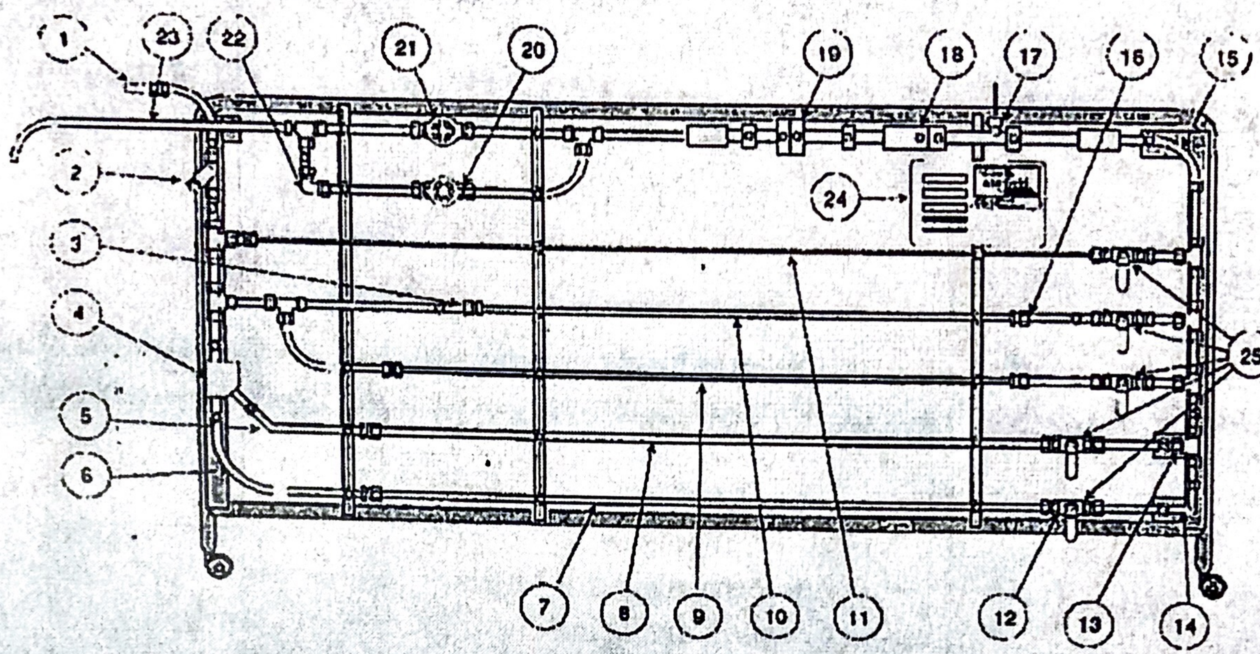


Figure 1: General Arrangement of C6-MKII-10 Fluid Friction Apparatus

The test pipes and fittings are mounted on a tubular frame carried castors. Water is fed in from the hydraulics bench via the barbed connector (1), flows through the network of pipes and fittings, and is fed back into the volumetric tank via the exit tube 23). The pipes are arranged to provide:

- An in-line strainer (2)
- An artificially roughened pipe (7)
- Smooth bore pipes of 4 different diameters (8), (9), (10) and (11)
- A long radius 90° bend (6)
- A short radius 90° bend (15)
- A 45° "Y" (4)
- A 45° elbow (5)
- A 90° "T" (13)

- A 90° mitre (14)
- A 90° elbow (22)
- A sudden contraction (3)
- A sudden enlargement (16)
- A pipe section made of clear acrylic with a Pitot static tube (17)
- A Venturi made of clear acrylic (18)
- An orifice meter made of clear acrylic (19)
- A ball valve (12)
- A globe valve (20)
- A gate valve (21)

Short samples of each size test pipe (24) are provided loose so that the students can measure the exact diameter and determine the nature of the internal finish. The ratio of the diameter of the pipe to the distance of the pressure tappings from the ends of each pipe has been selected to minimize end and entry effects.

A system of isolating valves (25) is provided whereby the pipe to be tested can be selected without disconnecting or draining the system. The arrangement also allows tests to be conducted on parallel pipe configurations.

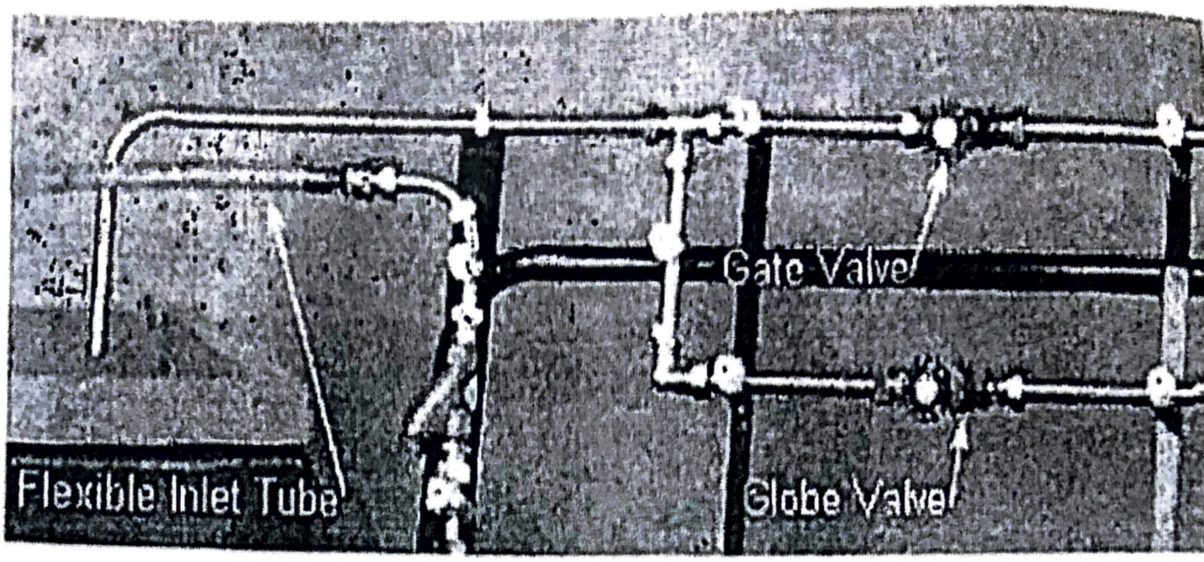
Each pressure tapping is fitted with a quick connection facility. Probe attachments with an adequate quantity of translucent polythene tubing are provided, so that any pair of pressure tappings can be rapidly connected to the pressure measurement system.

OPERATING THE EQUIPMENT

1. Controlling the Flow

Water is pumped through the Fluid Friction Apparatus using a centrifugal pump mounted on the underside of the hydraulics bench. The pump can be switched on and off using the Power switch indicated below. The Flow Control Valve should always be closed before starting the pump.

Water flows through the connector in the channel on the bench top, through the flexible connecting hose shown below and into the C6-MKI 1-10. It will then flow through whichever of the test pipes is selected, back through the acrylic pipe section and into the volumetric tank in the hydraulics bench.



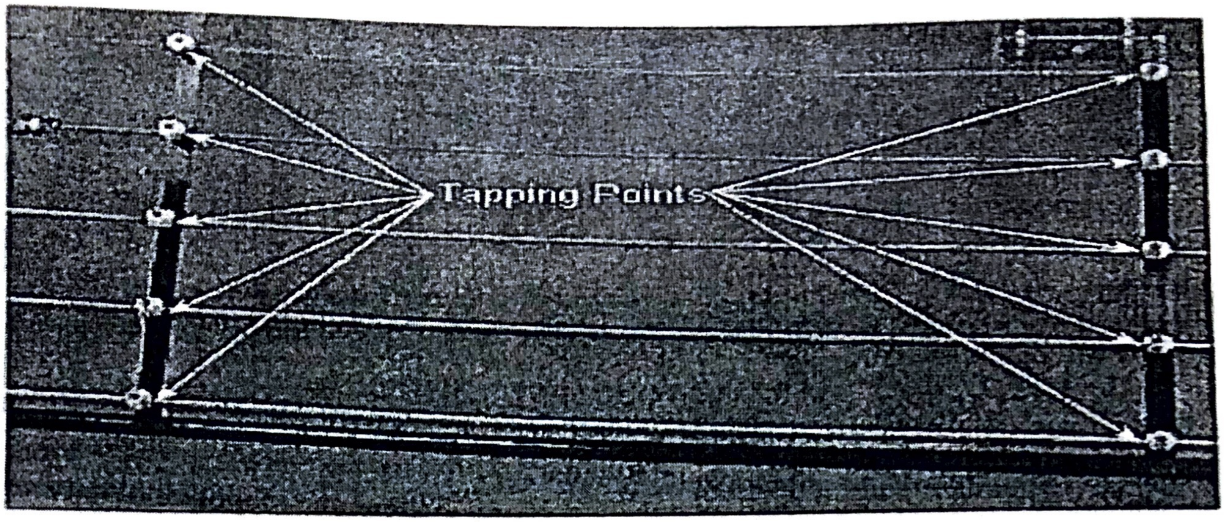
Flow rates through the apparatus may be adjusted by operation of the Control Valve on the hydraulics bench. Simultaneous operation of the flow control valve with the two outlet valves (gate and globe) shown above, will permit adjustment of the static pressure in the apparatus together with the flow rate. Using the three valves in combination it should be possible to achieve fine adjustment of the flow.

The flow path through the pipe friction network is controlled using the system of isolating valves shown below. By opening and closing these valves as appropriate it is possible to select flow through any combination of pipes.

2. Pressure Measurement

The head loss due to pipe friction is measured by taking pressure readings at different tapping points on the pipe network. In order to measure the pressure loss along a pipe, the pressure measurement device is connected to between a pair of tappings, using the tubing and connectors supplied.

Each pressure point on the apparatus is fitted with a self-sealing tapping point (see below). To connect a test probe to a pressure point once the pipe is primed, simply push the tip of the test probe into the pressure point until it latches. To disconnect a test probe from a pressure point, press the metal clip of the side of the pressure point to release the test probe. Both test probe and pressure point will seal to prevent loss of water.



Tapping Points

3. Operation with Manometers

Connect the flexible tubes supplied to the inlets at the bottom of the manometer and fit the quick release connectors to the ends of the tubes. Connect the manometer tubes to the pipe network at two tappings with a high pressure drop (e.g. either side of a partially closed valve) and start the pump. Water will be forced through the manometer, expelling the air in the pipes.

When all air bubbles have been expelled, disconnect the manometer from the pipe network. The quick release fittings will seal keeping the tubes full of water.

The pressurized water manometer incorporates a Schrader valve which is connected to the top manifold. This permits the levels in the limbs to be adjusted for measurement of small differential pressures at various static pressures.

The hand pump supplied will be required to effect reduction of levels at high static pressures. Alternatively a foot pump (not supplied) may be used.

Exercise A - Fluid Friction in a Smooth Bore Pipe

Objective

To determine the relationship between head loss due to fluid friction and velocity for flow of water through smooth bore pipes and to confirm the head loss predicted by a pipe friction equation.

Method

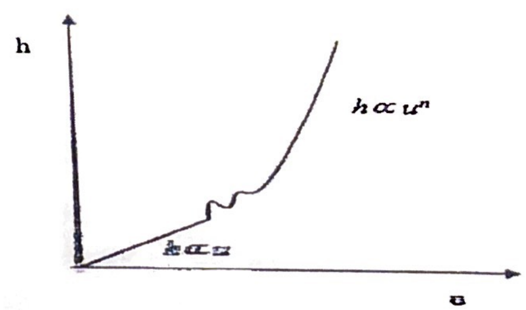
To obtain a series of readings of head loss at different flow rates through the four smooth bore test pipes.

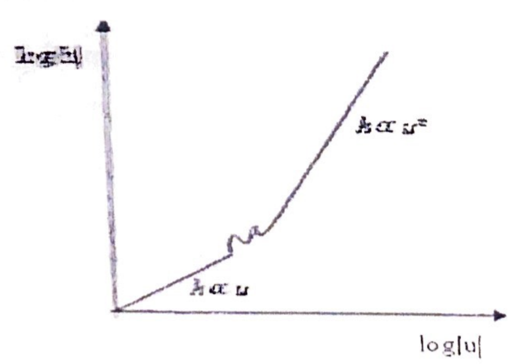
Theory

Professor Osborne Reynolds demonstrated that two types of flow may exist in a pipe.

1. Laminar flow at low velocities where $h \propto u$.
2. Turbulent flow at higher velocities where $h \propto u^n$

Where h is the head loss due to friction and u is the fluid velocity. These two types of flow are separated by a transition phase where no definite relationship between h and u exists. Graphs of h versus u and log h versus log u show these zones.





Furthermore, for a circular pipe flowing full, the head loss due to friction may be calculated from the formula:

$$h = \frac{4\,f\,L\,u^2}{2\,g\,d} \quad \text{or} \quad \frac{\lambda\,L\,u^2}{2\,g\,d} \qquad (1)$$

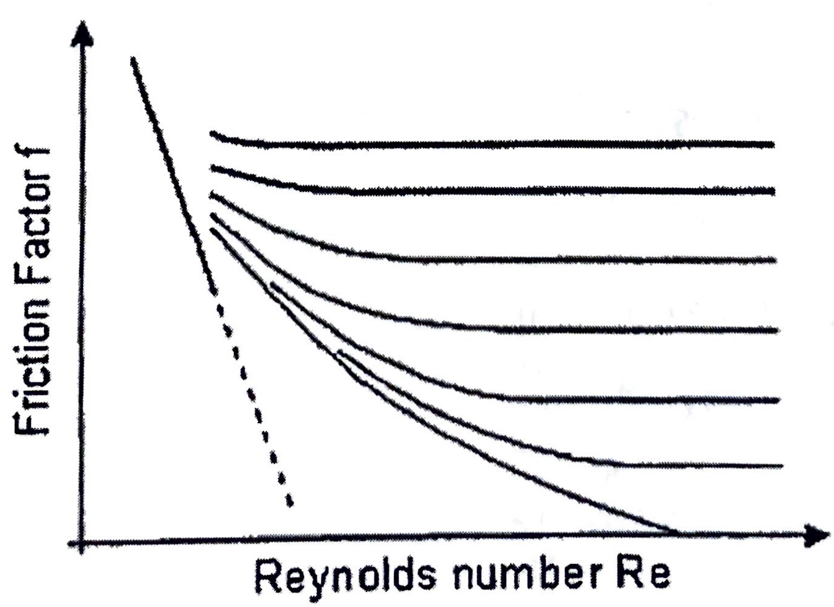
where L is the length of the pipe between tappings, d is the internal diameter of the pipe, u is the mean velocity of water through the pipe in m/s, g is the acceleration due to gravity in m/s2 and f is pipe friction coefficient. Note that the American equivalent of the British term f is λ where $\lambda = 4f$.

The Reynolds' number, Re, can be found using the following equation:

$$Re = \frac{\rho\,u\,d}{\mu} \qquad (2)$$

where μ is the molecular viscosity (1.15 x 10-3 Ns/m2 at 15°C) and ρ is the density (999 kg/m3 at 15°C).

Having established the value of Reynolds' number for flow in the pipe, the value of f may be determined using a Moody diagram, a simplified version of which is shown below.



Equation (1) can be used to determine the theoretical head loss.

L = 1 meter

$\rho = 999\ kg/m^3$

$\mu = 1.15 \times 10^{-3}\ \frac{NS}{m^2}$

At = 15.8

$\varepsilon = 0.015 \times 10^{-3}$ meter

PROCEDURE

1. Prime the pipe network with water. Open and close the appropriate valves to obtain flow of water through the required test pipe.

2. Take readings at several different flow rates, altering the flow using the control valve on the hydraulics bench (ten readings is sufficient to produce a good head-flow curve).

3. Measure flow rates using the volumetric tank. For small flow rates use the measuring cylinder. Measure head loss between the tappings using pressurized water manometer.

4. Obtain readings on all four smooth test pipes.

RESULTS

$Q = V \times A$. $V = \frac{Q}{A}$

Compare the values of head loss determined by calculation with those measured using the manometer.

Volume V (Liters)	Time T (Sec.)	Flow Rate Q (m³/Sec.)	Pipe Diam. d (m)	Velocity u (m/Sec.)	Reynolds Re	λ	Calculated Head Loss	Measured Head Loss
		$V \times 10^{-3} / T$		$4Q/\pi d^2$	$\rho u d/\mu$	From Moody Diagram	$\lambda L u^2/2gd$	h
3	5.13	5.85×10^{-4}	5			0.14		
			5					
3	5.13	5.85×10^{-4}	8					
			8					
3	5.13	5.85×10^{-4}	11					
			11					
3	5.13	5.85×10^{-4}	17					
			17					
3	5.13	5.85×10^{-4}	15					
			15					

Exercise B - Head Loss Due to Pipe Fittings

Objective

To determine the head loss associated with flow of water through standard fittings used in plumbing installations.

Method

Measure the differential head between tappings on fittings and test valves.

Theory

Head loss in a pipe fitting is proportional to the velocity head of the fluid flowing through the fitting:

$$h = \frac{Ku^2}{2g} \qquad (1)$$

where K is the fitting 'loss factor', u is the mean velocity of water through the pipe in m/s and g is the acceleration due to gravity in m/s^2.

Note: A flow control valve is a pipe fitting which has an adjustable 'K' factor. The minimum value of 'K' and the relationship between stem movement and 'K' factor are important in selecting a valve for an application.

Equipment Setup

Additional equipment required: Stop watch.

The following fittings and valves are available for test (numbers in brackets refer to Figure 1 in the Equipment Diagrams):

Sudden Contraction (3)

Sudden Enlargement (16)

Ball Valve (12)

45° Elbow (22)

45° Mitre (5)

45° Y Junction (4)

Gate Valve (21)

Globe Valve (20)

In Line Strainer (2)

90° Elbow (22)

90° Short Radius Bend (15)

90° Long Radius Bend (6)

90° T Junction (13)

If using the C6-50 Data Logging accessory, ensure that the console is powered and connected to the PC via the USB connection. Load the C6-304 software and choose Exercise B.

Taking a Set of Results

Prime the network with water. Open and close the appropriate valves to obtain flow of water through the required fitting.

Take readings at several different flow rates, altering the flow using the control valve on the hydraulics bench.

Measure flow rates using the volumetric tank (if using the C6-304 software, flow rate id measured directly).

Measure differential head between tappings on each fitting using the hand held pressure meter, sensors or pressurised water manometer.

Processing Results

All readings should be tabulated as follows:

Volume V [litres]	Time T [secs]	Flow rate Q [m³/s]	Pipe Dia d [m]	Velocity u [m/s]	Velocity Head hv [mH₂O]	Measured Head Loss h [mH₂O]	Fitting Factor K	Valve Position (valves only)
		$\frac{V \times 10^3}{T}$		$\frac{4Q}{\pi d^2}$	$\frac{u^2}{2g}$	$(h_C - h_D)$	$\frac{h}{hv}$	

Confirm that K is a constant for each fitting over the range of test flow rates.

Plot a graph of K factor against valve opening for each test valve. Note the differences in characteristic.

Exercise C - Fluid Friction in a Roughened Pipe

Objective

To determine the relationship between fluid friction coefficient and Reynolds' number for flow of water through a pipe having a roughened bore.

Method

To obtain a series of readings of head loss at different flow rates through the roughened test pipes.

Theory

The head loss due to friction in a pipe is given by:

$$h = \frac{4fLu^2}{2gd} \quad \text{or} \quad \frac{\lambda L u^2}{2gd} \qquad (1)$$

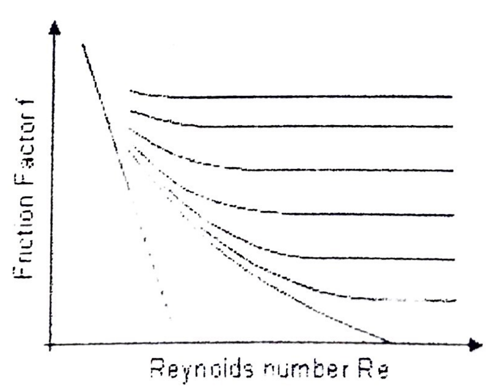
where L is the length of the pipe between tappings, d is the internal diameter of the pipe, u is the mean velocity of water through the pipe in m/s, g is the acceleration due to gravity in m/s² and f is pipe friction coefficient. Note that the American equivalent of the British term f is λ where $\lambda = 4f$.

The Reynolds' number, Re, can be found using the following equation:

$$\mathrm{Re} = \frac{\rho u d}{\mu} \qquad (2)$$

where μ is the molecular viscosity (1.15×10^{-3} Ns/m^2 at 15°C) and ρ is the density (999 kg/m^3 at 15°C).

Having established the value of Reynolds' number for flow in the pipe, the value of f may be determined using a Moody diagram, a simplified version of which is shown below.



Use equation (1) to determine the theoretical head loss.

Equipment Set Up

Additional equipment required: Stop watch, Internal Vernier calliper.

Open and close the ball valves as required to obtain flow through only the roughened pipe.

If using the C6-50 Data Logging accessory, ensure that the console is powered and connected to the PC via the USB connection. Load the C6-304 software and choose Exercise C.

Taking a Set of Results

Prime the pipe network with water. Open and close the appropriate valves to obtain flow of water through the roughened pipe.

Take readings at several different flow rates, altering the flow using the control valve on the hydraulics bench.

Measure flow rates using the volumetric tank (if using the C6-304 software, flow rate is measured directly). For small flow rates use the measuring cylinder.

Measure head loss between the tappings using the hand-held meter, sensors or manometer as appropriate.

Estimate the nominal internal diameter of the test pipe sample using a Vernier calliper (not supplied). Estimate the roughness factor k/d.

Processing Results

All readings should be tabulated as follows:

Volume	Time	Flow rate	Pipe Diam.	Velocity	Reynolds Number	Measured Head Loss	Friction Coefficient
V	T	Q	d	u	Re	h	f
[litres]	[secs]	[m³/s]	[m]	[m/s]		[m H_2O]	
		$\frac{V \times 10^{-3}}{T}$		$\frac{4Q}{\pi d^2}$	$\frac{\rho u d}{\mu}$	$(h_C - h_D)$	$\frac{g d h}{2 l u^2}$

Pipe length *l* = m

Roughness height *k* = m

Plot a graph of pipe friction coefficient versus Reynolds' number (log scale).

Note the difference from the smooth pipe curve on the Moody diagram when the flow is turbulent.

Exercise D - Flow Measurement Using Differential Head

Objective

To demonstrate the application of differential head devices in the measurement of flow rate and velocity of water in a pipe.

Method

To obtain a series of readings of head loss at different flow rates through an orifice plate, a Venturi meter and a Pitot tube.

Theory

For an orifice plate or Venturi, the flow rate and differential head are related by Bernoulli's equation with a discharge coefficient added to account for losses:

$$Q = Cd \cdot A_0 \sqrt{\frac{2g \cdot \Delta h}{(A_0 / A_1)^2 - 1}} \qquad (1)$$

where Q is the flow rate in m^3/s, Cd is the discharge coefficient (Cd = 0.98 for a Venturi, 0.62 for an orifice plate), A_0 is the area of the throat or orifice in m^2 (d_0 = 14mm for the Venturi, 20mm for the orifice plate), A_1 is the area of the pipe upstream m^2 (d_1 = 24mm), Δh is the differential head in metres of water and g is the acceleration due to gravity in m/s^2.

For a Pitot tube, the differential head measured between the total and static tappings is equivalent to the velocity head of the fluid:

$$\frac{u^2}{2g} = (h_1 - h_2) \qquad (2)$$

$$u = \sqrt{2g(h_1 - h_2)} \qquad (3)$$

where u is the mean velocity of water through the pipe in m/s, $h_1 - h_2$ is the differential head in metres of water and g is the acceleration due to gravity in m/s^2.

Equipment Set Up

Additional equipment required: Stop watch, Internal Vernier calliper.

Open all ball valves to achieve the minimum restriction to flow.

If using the C6-50 Data Logging accessory, ensure that the console is powered and connected to the PC via the USB connection. Load the C6-304 software and choose Exercise D.

Taking a Set of Results (using the Venturi and orifice plate)

Prime the pipe network with water. Open the appropriate valves to obtain flow of water through the flowmeters.

Obtain readings from the Venturi and orifice plate at different flow rates from minimum to maximum flow, altering the flow rate using the control valve on the hydraulics bench. At each setting measure the differential head produced by each flowmeter, the head loss across each flowmeter and the corresponding volume flowrate.

Note: To measure the differential head developed by the orifice plate or Venturi (for the purpose of flow measurement) connect the probes from the appropriate manometer to the two tappings on the flowmeter body, upstream and at the throat (do not use the downstream tapping in the pipe). To measure the head loss across the orifice plate or Venturi connect the probes from the water manometer to the upstream tapping on the flowmeter body and the tapping in the pipe downstream of the device (do not use the throat tapping).

Processing Results (for the Venturi and orifice plate)

All readings should be tabulated as follows:

Volume V [litres]	Time T [secs]	Flow rate Qm [m³/s]	Differential Head h [m H_2O]	Flowrate calculated Qc [m³/s]	Head Loss hl [m H_2O]
		$\frac{V \times 10^{-3}}{T}$		Eqn (1)	$(h_A - h_B)$

Compare each calculated flowrate with the actual flowrate measured.

Compare the head loss across the Venturi and orifice at the same flowrate.

Compare the differential head across the Venturi and orifice plate at the same flowrate.

Comment on the differences in the two devices and their suitability for flow measurement.

Use the theory covered by Experiment C to determine the K factor for the two flowmeters.

Taking a Set of Results (for the Pitot tube)

Ensure that the nose of the Pitot tube is directly facing the direction of flow and located on the centre line of the pipe.

Obtain readings from the Pitot tube at different flowrates from minimum to maximum flow. At each setting of the flow control valve measure the differential head produced by the Pitot tube and the corresponding volume flowrate.

At the maximum flow setting unscrew the sealing gland sufficiently to allow the Pitot tube to move. Traverse the tube across the diameter of the pipe and observe the

Obtain readings from the Venturi and orifice plate at different flow rates from minimum to maximum flow, altering the flow rate using the control valve on the hydraulics bench. At each setting measure the differential head produced by each flowmeter, the head loss across each flowmeter and the corresponding volume flowrate.

Note: To measure the differential head developed by the orifice plate or Venturi (for the purpose of flow measurement) connect the probes from the appropriate manometer to the two tappings on the flowmeter body, upstream and at the throat (do not use the downstream tapping in the pipe). To measure the head loss across the orifice plate or Venturi connect the probes from the water manometer to the upstream tapping on the flowmeter body and the tapping in the pipe downstream of the device (do not use the throat tapping).

Processing Results (for the Venturi and orifice plate)

All readings should be tabulated as follows:

Volume V [litres]	Time T [secs]	Flow rate Qm [m³/s]	Differential Head h [m H_2O]	Flowrate calculated Qc [m³/s]	Head Loss hl [m H_2O]
		$\frac{V \times 10^{-3}}{T}$		Eqn (1)	$(h_A - h_B)$

Compare each calculated flowrate with the actual flowrate measured.

Compare the head loss across the Venturi and orifice at the same flowrate.

Compare the differential head across the Venturi and orifice plate at the same flowrate.

Comment on the differences in the two devices and their suitability for flow measurement.

Use the theory covered by Experiment C to determine the K factor for the two flowmeters.

Taking a Set of Results (for the Pitot tube)

Ensure that the nose of the Pitot tube is directly facing the direction of flow and located on the centre line of the pipe.

Obtain readings from the Pitot tube at different flowrates from minimum to maximum flow. At each setting of the flow control valve measure the differential head produced by the Pitot tube and the corresponding volume flowrate.

At the maximum flow setting unscrew the sealing gland sufficiently to allow the Pitot tube to move. Traverse the tube across the diameter of the pipe and observe the

Figure 12.4 Moody diagram for friction factor for pipes.

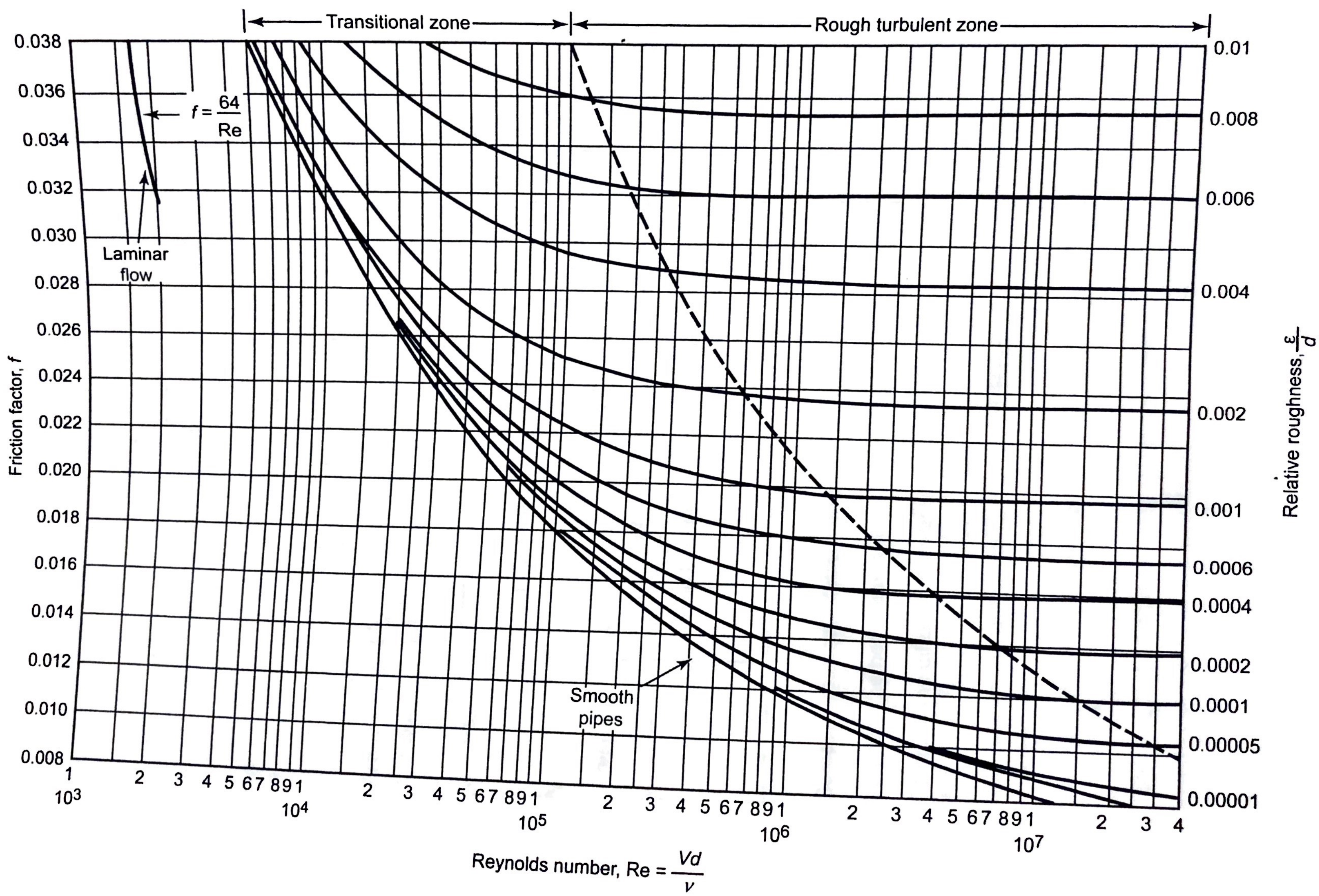


Figure 12.3 Nikuradse's experiment on smooth and sand-coated pipes.

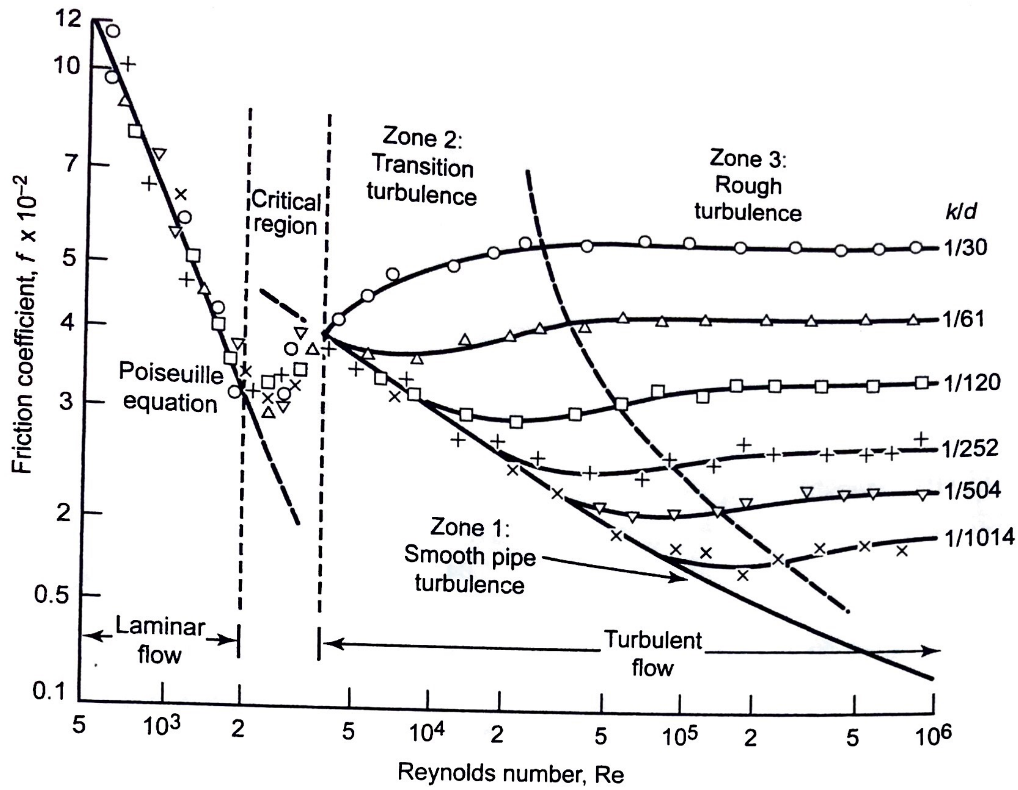


Table 12.1 Roughness Values for Pipes

Pipe Material	Equivalent Roughness, ε (ft)	Hazen-Williams Coefficient, C
PVC, plastic	Smooth	140
Brass, copper, aluminum, glass	Smooth	140
Dawn tubing	5×10^{-6}	—
Cast iron		
new	8.0×10^{-4}	130
old		100
Galvanized iron/ductile pipe	5.0×10^{-4}	120
Asphalted iron	4.0×10^{-4}	—
Wrought iron	1.5×10^{-4}	—
Commercial and welded steel	1.5×10^{-4}	120
Wood stave	20.0×10^{-4}	120
Concrete	40.0×10^{-4}	130
Riveted steel	60.0×10^{-4}	110
Brick sewer	—	100

Table 12.2 Minor Head Loss Coefficients

Item	Loss Coefficient, K
Entrance from tank to pipe	
Flush connection	0.5
Projecting connection	0.8
Exit from pipe to tank	1.0
Sudden contraction $(h_m = KV_2^2/2g)$	
$d_2/d_1 = 0.2$	0.48
$d_2/d_1 = 0.4$	0.42
$d_2/d_1 = 0.6$	0.32
$d_2/d_1 = 0.8$	0.20
$d_2/d_1 = 0.9$	0.05
Sudden enlargement $(h_m = KV_1^2/2g)$	
$d_1/d_2 = 0.9$	0.04
$d_1/d_2 = 0.8$	0.13
$d_1/d_2 = 0.6$	0.41
$d_1/d_2 = 0.4$	0.71
$d_1/d_2 = 0.2$	0.92
90° bend and 180° return—threaded	1.5
45° bend—threaded	0.4
90° bend and 180° return—flanged	0.3
45° bend—flanged	0.3
Tee—threaded	
through flow	0.9
branched flow	2.0
Tee—flanged	
through flow	0.2
branched flow	1.0
Gate valve (open)	0.19
Check valve (open)	2.0
Globe valve (open)	10.0
Angle valve (open)	2.0
Butterfly valve (open)	0.3

Note: Subscript 1 refers to upstream and 2 refers to downstream section.

REPORT

Report the following information in the report or field records, or both:

1. Location of test site.

2. Dates of test, start and finish.

3. Name(s) of team integrant(s).

5. Description of the experiment.

6. Show results and calculations.

7. Plot a graph of h versus u for each size of pipe. Identify the laminar, transition and turbulent zones on the graphs. Confirm that the graph is a straight line for the zone of laminar flow $h \propto u$.

8. Plot a graph of log h versus log u for each size of pipe. Confirm that the graph is a straight line for the zone of turbulent flow $h \propto u^n$. Determine the slope of the straight line to find n.

9. Estimate the value of Reynolds number ($Re = \rho u d / \mu$) at the start and finish of the transition phase. These two values of **Re** are called the upper and lower critical velocities.

10. Confirm that the head loss can be predicted using the pipe friction equation provided the velocity of the fluid and the pipe dimensions are known.

11. Conclusion.

Note: It is assumed that the molecular viscosity μ is 1.15×10^{-3} Ns/m² at 15°C and the density ρ is 999 Kg/m³ at 15°C.