Experiment (12): Major losses

Introduction:
When a fluid is flowing through a pipe, it experiences some resistance due to which some of energy (head) of fluid is lost. Energy loss through friction in the length of pipeline is commonly termed the major loss \( (h_f) \) which is the loss of head due to pipe friction and to viscous dissipation in flowing water.

The resistance to flow in a pipe is a function of the pipe length, pipe diameter, mean velocity, properties of the fluid and roughness of the pipe (if the flow is turbulent), but it is independent of pressure under which the water flows.

Friction head losses in straight pipes of different sizes can be investigated over a range of Reynolds' numbers from \( 10^3 \) to nearly \( 10^5 \), 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.

Exercise A (Fluid friction in a smooth bore pipe)

Purpose:
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.

Apparatus:
1. Fluid friction apparatus.
2. Hydraulics bench to supply water to the fluid friction apparatus (the flow of water can be measured by timed volume collection).

Figure 1: Fluid friction apparatus
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 \( h \propto un \)

Where \( h \) is the head less 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:

\[
h = \frac{fL \mu u^2}{2gd}
\]

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/s\(^2\) and \( f \) is pipe friction coefficient.

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

\[
Re = \frac{\rho vd}{\mu}
\]

Where \( \mu \) is the molecular viscosity \( (1.15 \times 10^{-3} \text{ Ns/m}^2 \text{ at 15°C}) \) and \( \rho \) is the density \( (999 \text{ kg/m}^3 \text{ at 15°C}) \).

Having established the value of Reynolds' number for flow in the pipe, the value of \( f \) may be determined using a Moody diagram as shown below.
Equipment Set Up:
Additional equipment required: Stop watch, Internal Vernier calliper.
Arrange the valves on the equipment to allow flow through only the test pipe under observation.
If using the data logging accessory, ensure that the console is powered and connected to the PC via the USB connection. Load the software and choose a suitable exercise.

Procedures:
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 (if using a software, flow rate is measured directly). For small flow rates use the measuring cylinder. Measure head loss between the tappings using the portable pressure meter or pressurised water manometer as appropriate.
4. Obtain readings on all four smooth test pipes.
5. Measure the internal diameter of each test pipe sample using a Vernier calliper.
Results:

All readings should be tabulated as follows:

<table>
<thead>
<tr>
<th>Volume $V$ (liters)</th>
<th>Time $T$ (Sec)</th>
<th>Flow rate $Q$ (m$^3$/s)</th>
<th>Pipe diam. $d$ (m)</th>
<th>Velocity $u$ (m/s)</th>
<th>Reynolds No $Re$</th>
<th>$f$</th>
<th>Calculated head loss $h_c$ (m H$_2$O)</th>
<th>Measured head loss $h$ (mH$_2$O)</th>
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<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>$\frac{\rho ud}{\mu}$</td>
<td>From Moody Diagram</td>
<td>$\frac{fLu^2}{2gd}$</td>
<td>$(h_c-h_0)$</td>
</tr>
</tbody>
</table>

1. Plot a graph of $h$ versus $u$ for each size of pipe. Identify the laminar, transition and turbulent zones on the graphs.
2. Confirm that the graph is a straight line for the zone of laminar flow $h \propto u$.
3. 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 $n$.
4. Estimate the value of Reynolds number ($Re = \frac{\rho ud}{\mu}$) at the start and finish of the transition phase. These two values of $Re$ are called the upper and lower critical velocities.
5. Compare the values of head loss determined by calculation with those measured using the manometer.
6. 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.

It is assumed that the molecular viscosity $\mu$ is $1.15 \times 10^{-3}$ Ns/m$^2$ at 15°C and the density $\rho$ is 999 kg/m$^3$ at 15°C.
Exercise B (Fluid friction in a roughened pipe)

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

Apparatus:
1. Fluid friction apparatus.
2. Hydraulics bench to supply water to the fluid friction apparatus (the flow of water can be measured by timed volume collection).

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

\[ h = \frac{fL u^2}{2gd} \]

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/s\(^2\) and \( f \) is pipe friction coefficient.

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

\[ Re = \frac{\rho vd}{\mu} \]

Where \( \mu \) is the molecular viscosity (1.15 x 10\(^{-3}\) Ns/m\(^2\) at 15°C) and \( \rho \) 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.

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 Data Logging accessory, ensure that the console is powered and connected to the PC via the USB connection. Load the software and choose a suitable exercise.

Procedures:
1. Prime the pipe network with water. Open and close the appropriate valves to obtain flow of water through the roughened pipe.
2. Take readings at several different flow rates, altering the flow using the control valve on the hydraulics bench.
3. Measure flow rates using the volumetric tank (if using the software, flow rate is measured directly). For small flow rates use the measuring cylinder.
4. Measure head loss between the tappings using the hand-held meter, sensors or manometer as appropriate.
5. Estimate the nominal internal diameter of the test pipe sample using a Vernier calliper (not supplied). Estimate the roughness factor e/d.

**Results:**

All readings should be tabulated as follows:

<table>
<thead>
<tr>
<th>Volume V (liters)</th>
<th>Time T (Sec)</th>
<th>Flow rate Q (m³/s)</th>
<th>Pipe diam. d (m)</th>
<th>Velocity u (m/s)</th>
<th>Reynolds No Re</th>
<th>Measured head loss h (mH₂O)</th>
<th>Friction coefficient f</th>
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1. Plot a graph of pipe friction coefficient versus Reynolds’ number (log scale).
2. Note the difference from the smooth pipe curve on the Moody diagram when the flow is turbulent.