# H408

## Fluid Friction Apparatus

# User Guide



TecQuipment has taken care to make the contents of this manual accurate and up to date. However, if you find any errors, please let us know so we can rectify the problem.

TecQuipment supply a Packing Contents List (PCL) with the equipment. Carefully check the contents of the package(s) against the list. If any items are missing or damaged, contact TecQuipment or the local agent.

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# Contents

# SECTION 1.0 INTRODUCTION

*Figure 1 The H408 Fluid Friction Apparatus*

The TecQuipment H408 Fluid Friction Apparatus allows students to investigate flow, flow measurement techniques and losses in a wide variety of pipes and fittings.

The apparatus has three colour coded circuits each fitted with a different control valve and a selection of pipes and pipe fittings. One of the circuits include interchangeable sections, with further selections of pipe components. One of these interchangeable sections includes a Pitot Assembly with traversing mechanism.

Numbered pressure tappings are fitted at all the important points, for measurement of the pressure change along each pipe section or pipe component. Each pressure tapping includes a special self sealing connector.

To measure the pressure change across each pipe section or components, a free standing 3 way Piezometer unit is supplied. To measure the higher differential pressure across the valves and strainer, a differential pressure gauge is included. Suitable lengths of connecting pipes are supplied with the apparatus.

TecQuipment recommend that the apparatus is used with the TecQuipment H1 or H1d hydraulic bench for water supply and flow measurement, see '**External Cold Water Supply**' on page 8. For very low flow rate measurement a 1000 mL measuring cylinder (supplied) allows a more accurate volume/time method when used in conjunction with the hydraulic bench supply.

The pipe sections and pipe components include:

- A roughened pipe and smooth pipes of different internal diameters
- A selection of bends, an elbow and a mitre corner
- Three different types of valve
- Orifice and Venturi meters
- An in-line Strainer supplied with two different filters
- Sudden expansion and sudden contractions

# SECTION 2.0 DESCRIPTION OF PARTS

## *2.1 Pipes and Tappings*

Table 1 lists all the pipes and fittings on the apparatus, as well as their respective tapping numbers. Note that tappings 18 and 19 are linked.

| Item | Details | Tapping Numbers | Distances Between Tappings |
|---|---|---|---|
| Gate Valve | | 1, 2 | - |
| Globe Valve | | 3, 4 | - |
| Ball Valve | | 5, 6 | - |
| Smooth Pipe | 17 mm Diameter Bore | 7, 8 | 912 mm |
| Sudden Enlargement | 13.6 mm to 26.2 mm | 9, 10 | - |
| Sudden Contraction | 26.2 mm to 13.6 mm | 11, 12 | - |
| Smooth Pipe | 26.2 mm Diameter Bore | 10, 11 | 912 mm |
| Smooth Pipe | 13.6 mm Diameter Bore | 13, 14 | 912 mm |
| Radius Bend | 50 mm | 15, 16 | 920 mm |
| Radius Bend | 100 mm | 17, 18 | 864 mm |
| Radius Bend | 150 mm | 19, 4 | 652 mm |
| Mitre Corner | | 20, 21 | - |
| Elbow | 13.6 mm Radius | 22, 23 | - |
| Orifice | 20 mm Diameter | 24, 25 | - |
| Expansion | 26 mm to 52 mm | 26, 27 | - |
| Venturi | $d_1$ = 26 mm Diameter<br>$d_2$ = 16 mm Diameter | 28, 29 | - |
| Rough Pipe | 17 mm Diameter Bore<br>14 mm Effective Diameter | 30, 31 | 200 mm |
| Strainer | Includes Two Different Filters | 32, 33 | - |
| Smooth Pipe | 4 mm Diameter Bore | 34, 35 | 350 mm |
| Inlet Pipe | Coloured White | - | - |
| Outlet Pipe | Coloured Black | - | - |

*Table 1 Pipe Fittings and Their Tappings*

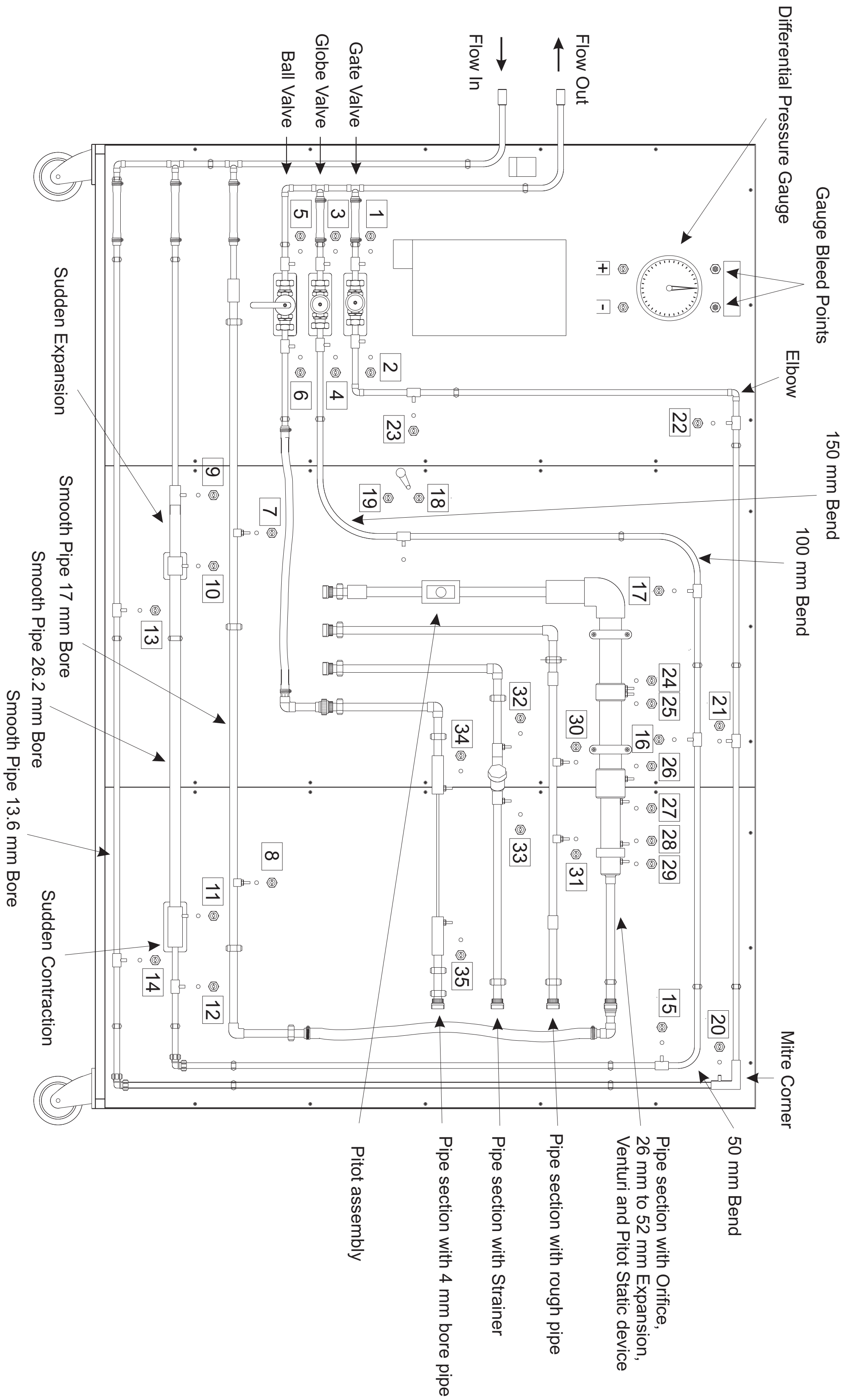


*Figure 2 Layout of the H408*

## 2.2 The Orifice and Venturi Meters

One of the interchangeable pipe sections includes an orifice, a venturi and an expansion piece. Figure 3 shows the section and its equivalent internal arrangement.

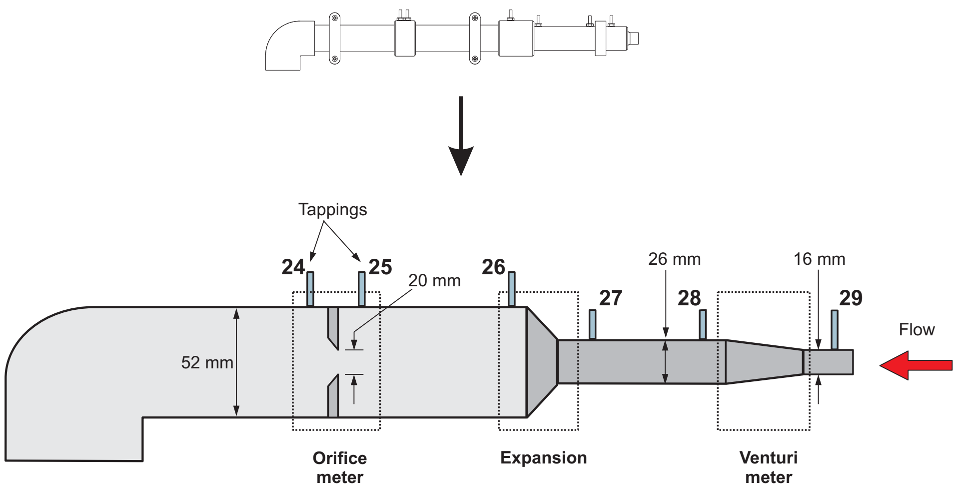


*Figure 3 The Orifice and Venturi Meters - Equivalent Diagram*

## 2.3 The Tappings

Each tapping has a small check valve. To connect to the tapping, simply push the metal tail piece of a connecting pipe into the tapping. To remove, gently squeeze the plastic halves of the tapping together.

## 2.4 The Grey Circuit

The Grey coloured pipe circuit includes four interchangeable sections. They are separate and interchangeable so that only one item can be connected at a time unlike the items in the other two circuits. This is because the interchangeable sections would have an adverse effect on the flow rate, pressure or flow quality for subsequent sections. To connect each interchangeable section, simply unscrew the quick couplers at the ends of the two flexible pipe sections and reconnect them to the ends of the chosen interchangeable section (see Figure 4).

### The Strainer

The Strainer is supplied with two different plastic filters, one with 1.4 mm diameter holes and the other with 0.5 mm diameter holes.

*Figure 4 Use the Quick Couplings to Connect to the Chosen Interchangeable Section of the Grey Circuit*

## *2.5 The Valves*

The three valves fitted to the apparatus are typical valves, made from Nickel Plated Brass or Bronze. The Globe valve is a similar design to domestic taps, where a circular washer is forced onto a circular valve seat to stop the flow. The flow is forced through a difficult route around the body of this valve. The Ball valve is a similar design to that used to shut off a domestic gas supply, it comprises of a sphere which rotates through 90 degrees inside the valve body. The sphere has a hole bored through it which is equal in diameter to the entrance and exit ports of the valve, so that it causes no interruption to the flow when it is fully open. The Gate valve is a very simple design, a 'gate' simply blocks the flow when it is forced down into position across the body of the valve.

The Globe and Gate valves need several turns of the handwheel to change between fully open and fully closed. The Ball valve only needs a 90 degree turn of its lever.

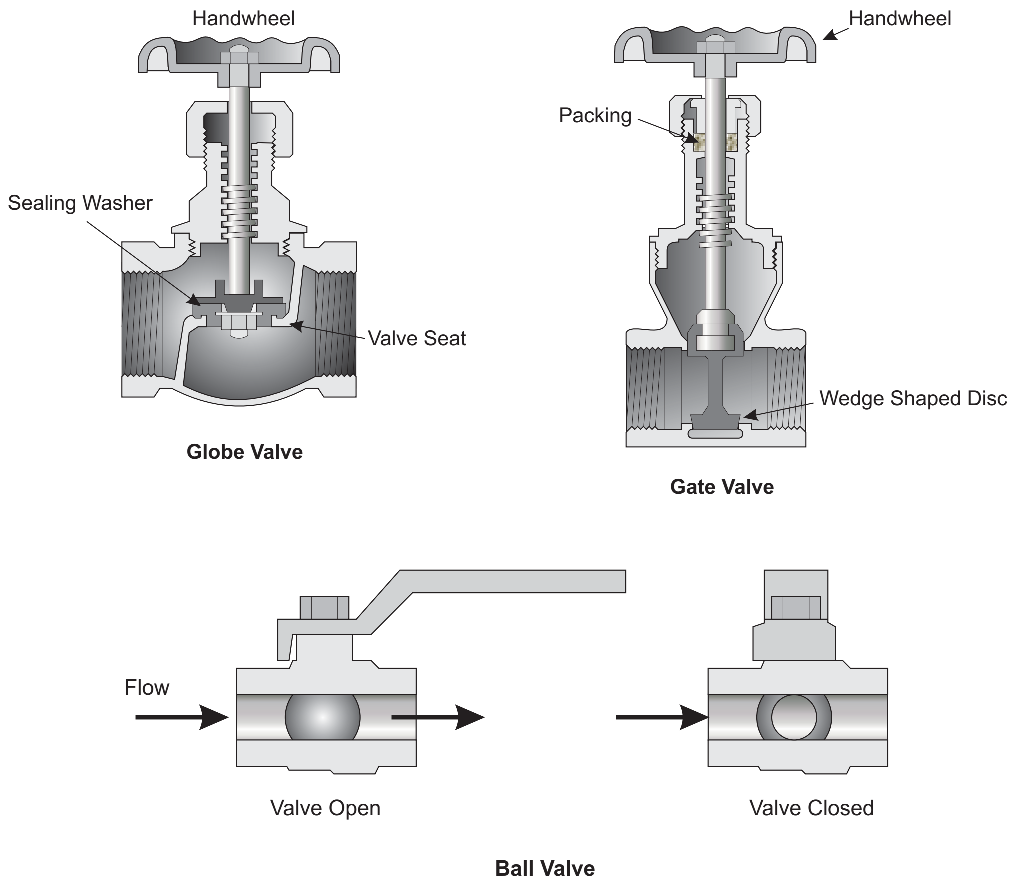


*Figure 5 Typical Valve Designs*

## 2.6 Optional Ancillaries

### External Cold Water Supply

The H408 apparatus needs an external source of clean cold water and a drain system with accurate flow measurement. TecQuipment manufacture two self contained hydraulic benches (not supplied) that perform this function, the H1 and the H1d (see Figure 6). Either of the benches is suitable.

**NOTE**

*If a mains water supply is used, it must include an accurate flow measurement device and must have a constant head and flow.*

*Figure 6 The H1 and H1d Hydraulic Benches Manufactured by TecQuipment (not supplied)*

## SECTION 3.0 INSTALLATION

The H408 is supplied already assembled, except for the Pitot Traverse Assembly and the feet of the H408 Set of Piezometers. The apparatus must then be connected to a suitable water supply, see '**External Cold Water Supply**' on page 8.

### Weights

H408: 130 kg

Set of Manometers: 27 kg

### To Fit the Pitot Traverse Assembly

The pitot tube moves across the inner diameter of the clear pipe on which it is fitted. The pitot tube is 1.6 mm diameter, so when it touches the walls of the pipe, the reading is actually at 0.8 mm. The pipe internal diameter is 21.85 mm. See Figure 7. The pitot is set by the manufacturer to read 0.8 mm when it touches the opposite pipe wall.

CAUTION

***Do not bend or force the pitot tube. It will be damaged beyond repair.***

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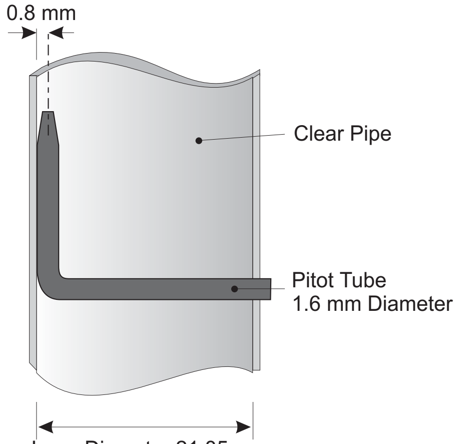


*Figure 7 The Pitot Tube Inside the Clear Pipe*

(a) Carefully insert the pitot tube into the lowest of the two holes in the clear pipe assembly, so the pitot tube points upwards (see Figure 8).

(b) Use the two 'U' bolts and the nuts and washers to securely clamp the Pitot Assembly to the tube (see Figure 9). Do not over tighten.

### To Reset the Pitot Assembly

If the pitot assembly 0.8 mm setting has been disturbed in any way, reset it as follows:

(a) Use a hexagon key to slacken the two grub screws (see Figure 10).

(b) Set the micrometer to 0.8 mm and carefully slide the micrometer and pitot tube until the pitot tube touches the opposite wall of the pipe.

(c) Hold the assembly in this position and re tighten the grub screws. The assembly is now reset.

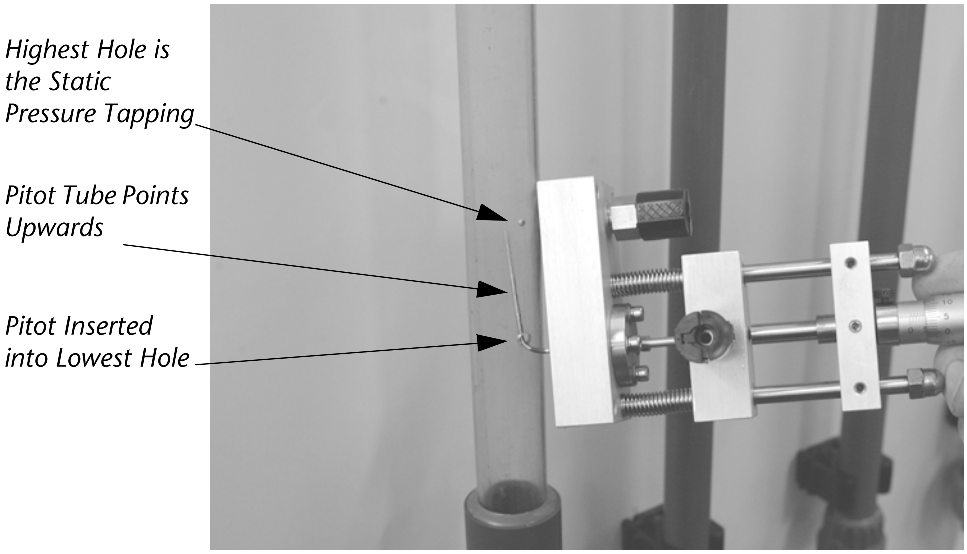


*Figure 8 Carefully Fit Pitot Into Clear Pipe Assembly*

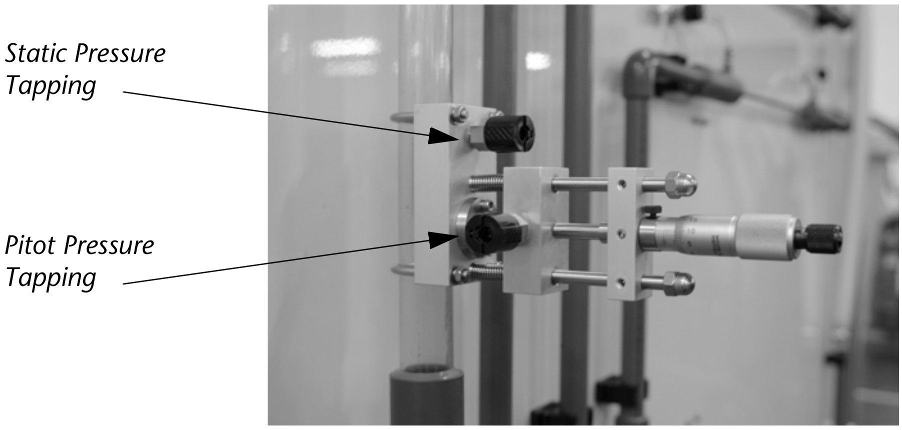


*Figure 9 Pitot Assembly Fitted Correctly*

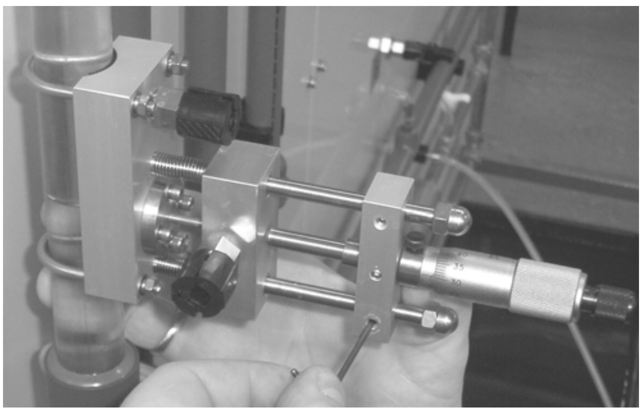

*Figure 10 Slacken the Grub Screws*

## To fit the Feet of the H408 Set of Piezometers

(a) Carefully lay the set of Piezometers face down on a table or bench

(b) Use a hexagon tool, a spanner and the fixings supplied to bolt the legs to the outside of the Piezometer frame.

## Connect to the Cold Water Supply

Make sure that all the flexible pipe fittings around these pipes and others are tight.

The inlet pipe is painted white and the outlet pipe is painted black. Connect these pipes to the supply and return on the TecQuipment Hydraulic Bench (or alternative supply and drain).

# SECTION 4.0 EXPERIMENTS AND THEORY

## 4.1 Setup

### Bleed Air From All Pipes and Instruments

Before taking any readings, bleed out any air trapped in the circuit, tapping points, connecting tubes, pressure gauges and Piezometer tubes.

**To bleed the connection pipes and piezometer:**

(1) Obtain a suitable bucket (10 Litre capacity) to avoid water spills.

(2) Connect and turn on the cold water supply to maximum flow, open the outlet valve on the circuit you are testing and wait for any trapped air to leave the circuit.

(3) Close the outlet valve on the circuit you are testing.

(4) Select suitable lengths of connecting tube and place one end into the bucket. Connect the other ends to the tapping points you wish to use.

(5) Wait until all the air has been forced out of the connecting pipes and quickly connect the free ends of the pipes from out of the bucket to the pair of tappings on the Piezometers you wish to use.

(6) Open the valve in the cap at the manifold (top of the Piezometer) and allow the piezometer to fill up. Release the valve when the Piezometer tubes are full of water.

(7) Reduce the cold water supply to a low rate of flow and open the outlet valve on the circuit you are testing.

(8) Open the valve cap on the Piezometer manifold again and allow the pressure to equalize in the tubes. Close the valve cap.

The self sealing tappings at the base of the Piezometers will help to keep the tubes full of water between experiments, as long as care is taken when you use the connecting tubes.

To alter the relative heights of the water column use the hand pump (supplied) to increase the manifold pressure, or release the pressure by pressing the centre of the valve in the manifold cap.

**To bleed the pressure gauge:**

(1) Use the lengths of pipe (supplied) to connect between the gauge tappings (marked '+' and '-) and the tappings at the valve you wish to monitor.

(2) Open the valve fully, increase the water supply to maximum flow and temporarily block the outlet pipe (hold your hand over the end of the pipe) to give maximum pressure in the circuit and at the valve.

(3) Unscrew the cap from each bleed valve (above the pressure gauge). Turn each of the caps around and press them into each bleed valve body, this opens the valves (see Figure 11).

(4) Keep the valves open until all the air has passed out of the pipe.

(5) Remove the block on the outlet pipe and adjust the flow to that needed for the experiment.

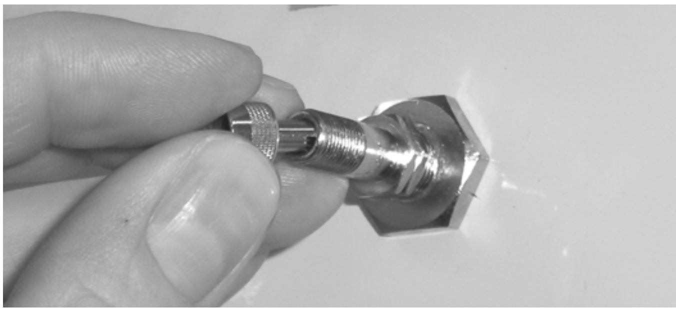

*Figure 11 Turn the Bleed Valve Caps around and Press them into the Valve Body.*

## 4.2 Useful Notes on Procedure

- Allow the flow to settle for several minutes before you take a reading from the Piezometers and the Pitot assembly.
- The surface of the water in the Piezometer tubes has a slight 'dish' shape or 'meniscus'- be consistent and always measure to the bottom of the meniscus.
- Lightly 'tap' the pressure gauge before you take its reading, it has a mechanical mechanism which may sometimes stick.
- Unless stated otherwise, set the maximum flow rate for the experiment at the cold water supply with the circuit valve fully open, then use the circuit valve to adjust the flow. This keeps the circuit pressure as high as possible and allows the flow rate to settle quickly.

## 4.3 Notation

The following symbols are used in the theory and calculations for the experiments:

| Symbol | Units | Description |
|---|---|---|
| $Q$ | Cubic Meters/Second ($m^3.s^{-1}$) | Volumetric Flow Rate |
| $h$ | Meters (m) | Head |
| $u$ | Meters/Second ($m.s^{-1}$) | Flow Velocity |
| $d$ | m | Pipe Diameter |
| $\nu$ | $m^2s^{-1}$ | Kinematic Viscosity |
| $l$ | Meters (m) | Length of pipe (between tappings) |
| $f$ | | Friction Factor |
| $g$ | $m.s^{-2}$ | Acceleration due to Gravity |
| $k$ | | Loss Factor |
| $k_s$ | m | Diameter of Sand Grains |
| $A$ | $m^2$ | Cross Sectional Area of Pipe |
| $Re$ | | Reynolds Number |

## *4.4 Losses in Straight Pipes Experiments*

The pipe experiments compare similar pipes in each of the circuits, this method allows the student to fully understand what happens and obtain accurate results before they move on.

### Aim

To determine the losses in smooth and roughened pipes.

### Procedure

(1) Prepare a blank table similar to Table 2.

(2) Close the Globe valve and the Ball valve (light blue and grey circuits). Open the Gate valve (dark blue circuit) half of a turn.

(3) Turn on the cold water supply and wait for any trapped air to leave the circuit, then close the Gate valve

(4) Connect one set of piezometer tubes to tappings 13 (upstream) and 14 (downstream), if necessary, bleed the pipes as describes in '**Setup**' on page 13.

(5) Use the hand pump if necessary to adjust the pressure in the Piezometer tubes until the levels are halfway up the scale. The level in each of the Piezometer tubes should be the same, if not then check for air bubbles or leaks.

(6) Fully open the gate valve and wait for the flow to settle. Record the readings on the Piezometer into Table 2.

(7) Use the Gate valve to reduce the flow rate in five suitable steps to give a good spread of results.

(8) Repeat for the other smooth pipes and the rough pipe. Use the measuring cylinder (supplied) and a stopwatch to measure the flow rate for the 4 mm pipe, as the flow rate is very low.

<table>
<tr><td colspan="3">Internal Diameter ($d$) =</td><td colspan="2">Area ($A$) =</td><td colspan="2">Length ($l$) =</td></tr>
<tr><td colspan="7">Pipe Type (Smooth/Rough) =</td></tr>
<tr><th rowspan="2">Time for 18 Litres (s)</th><th rowspan="2">Flow Rate ($Q$) ($m^3.s^{-1}$)</th><th colspan="3">Piezometer Readings</th><th rowspan="2">Flow Velocity ($m.s^{-1}$)</th><th rowspan="2">Re</th><th rowspan="2">$f$</th><th rowspan="2">Blasius $f$</th></tr>
<tr><th>Upstream Tapping (mm)</th><th>Downstream Tapping (mm)</th><th>Difference ($\Delta h$) (m)</th></tr>
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</table>

*Table 2 Blank Results Table*

### Results Analysis - Smooth Pipes

As fluid flows through a straight pipe, energy is dissipated due to turbulence and friction. This energy can be measured by the head loss for a length of pipe. Much research has been done into the losses in pipes, and it has been shown that the head loss, $h$, can be represented by a friction factor $f$, where

$$h = 4flu^2 / 2gd$$

(a) For each pipe, calculate the flow rate ($Q$) and hence the flow velocity ($u$) as below.

$$u = Q/A$$

To allow a meaningful comparison to be made between pipes of different diameter and different flow rates, the Reynolds number, Re, for each test point is calculated, where

$$\mathrm{Re} = ud/\nu$$

given that $\nu = 1.004 \times 10^{-6}$ for water at 20°C.

(b) Calculate the friction factor, $f$, and the Reynolds number, Re, for each of the smooth pipes at each flow rate.

For a smooth pipe, the friction factor is given by the empirical Blasius formula.

$$f = 0.079(\mathrm{Re})^{-1/4}$$

The smooth pipes used on the apparatus are good quality with a generally smooth internal surface.

(c) Calculate the Blasius friction factor for each test point and compare to the measured value of $f$. Do these values suggest that the pipes are perfectly smooth? From these calculations, what effect does the pipe diameter have on the apparent smoothness?

### Results Analysis - Roughened Pipes

Figure 13 shows a graph produced by the American engineer Lewis Moody (1880-1953) which shows the relationship between friction factor and Reynolds number for different levels of pipe roughness. The line for a smooth pipe is the same as the Blasius formula.

(a) From the recorded results, calculate the $f$ factor and the Reynolds number for the roughened pipe. This pipe is coated internally with sand that has an average grain size of 0.5 mm (see Figure 12). The effective pipe diameter is 14.0 mm, so $k_s/d = 0.036$.

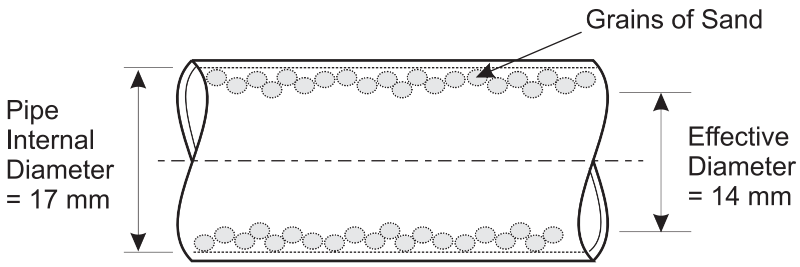


*Figure 12 Roughened Pipe*

(b) Compare the $f$ factor for the roughened pipe with the value from the Moody graph.

(c) Use the Moody graph, to estimate the surface roughness of the 'smooth pipes' used on the H408.

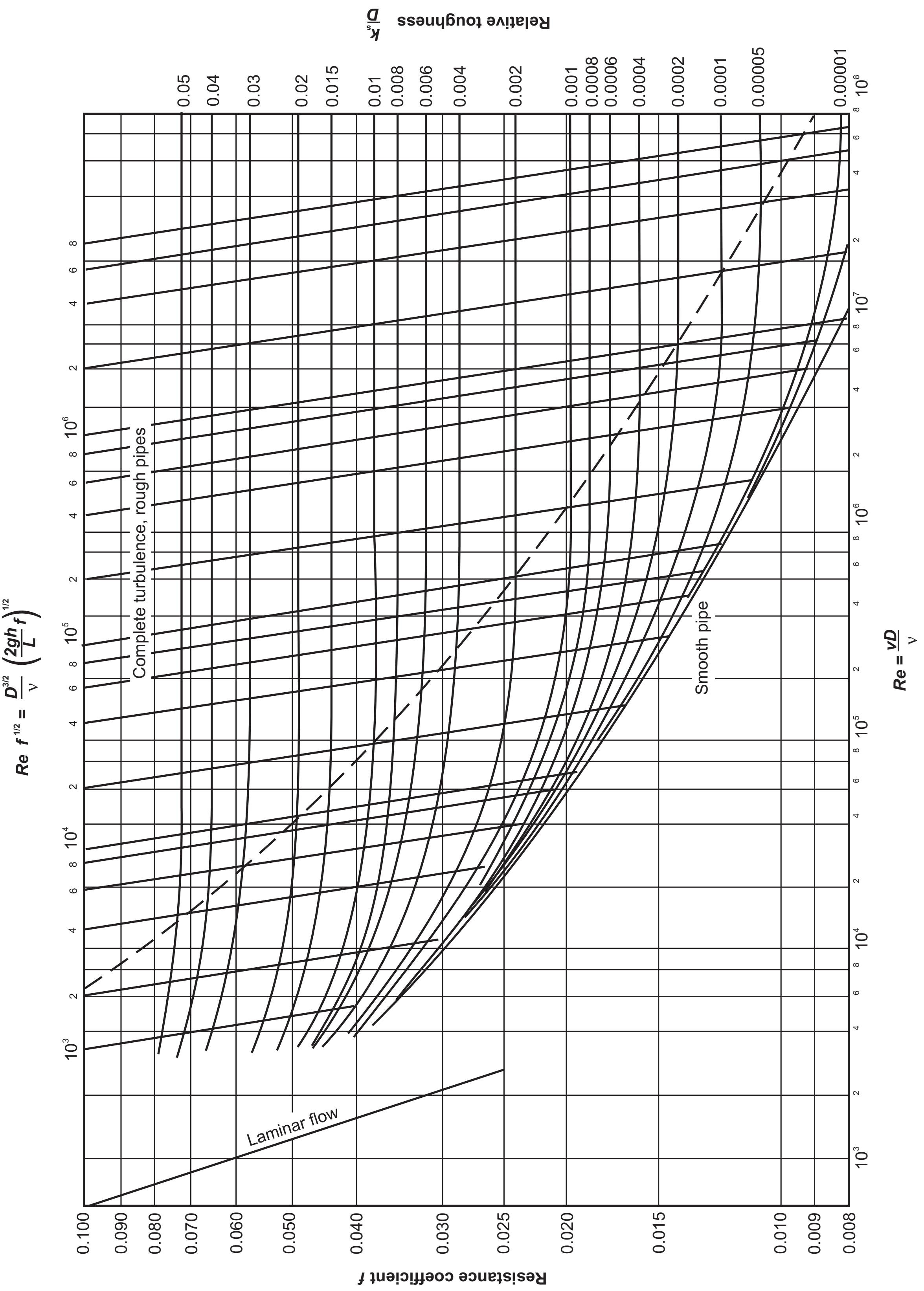


*Figure 13 Moody Chart*

## 4.5 Losses in Bends Experiments

This experiment tests all three of the different bends on the light blue circuit at the same time. It then tests the mitre and elbow on the dark blue circuit at the same time.

### Aim

To determine the head loss in bends and elbows.

### Procedure

(1) Prepare several blank tables similar to Table 3.

(2) Close the Gate valve and the Ball valve (dark blue and grey circuits). Open the Globe valve (light blue circuit) half of a turn.

(3) Turn on the cold water supply and wait for any trapped air to leave the circuit, then close the Globe valve.

(4) Connect each of the three sets of piezometer tubes to the tappings at each side of the bends (see Table 3). If necessary, bleed the pipes as describes in '**Setup**' on page 13.

(5) Use the hand pump if necessary to adjust the pressure in the Piezometer tubes until the levels are halfway up the scale. The level in each of the Piezometer tubes should be the same, if not then check for air bubbles or leaks. Note that tappings 18 and 19 are actually the same point, but are selected with the two way valve next to them. The valve handle points to the tapping that is connected. The valve is fitted to remove any possibility of pressure imbalance when tappings 4, 19, 18 and 17 are used at the same time.

(6) Fully open the Globe valve and wait for the flow to settle. Record the Peizometer readings into your tables.

(7) Use the Globe valve to reduce the flow rate in five suitable steps to give a good spread of results.

(8) Repeat for the mitre and elbow, but use the Gate valve to control the flow.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Internal Diameter ($d$) = | | | Pipe Length ($l$) = | | | | | | | | |
| Bend Radius ($R$) = | | | | | | | | | | | |
| **Time for 18 Litres (s)** | **Flow Rate ($Q$) ($m^3.s^{-1}$)** | **Piezometer Readings** | | | **Flow Velocity ($m.s^{-1}$)** | **Re** | **Blasius $f$** | **Straight Pipe Loss** | **Bend Loss** | $u^2/2g$ | $k_L$ |
| | | **Upstream Tapping (mm)** | **Downstream Tapping (mm)** | **Difference ($\Delta h$) (m)** | | | | | | | |
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*Table 3  Blank Results Table for Bends, Elbows and Corners*

## Results Analysis

When a fluid flows round a bend, energy losses occur due to flow separation, wall friction and some secondary-flow patterns caused by the bend (see standard texts). Bends may be characterised by the ratio of bend radius to internal diameter, $R/d$, where gently sweeping bends may have values of 10 or more, or an abrupt 'mitre' bend would be 0.

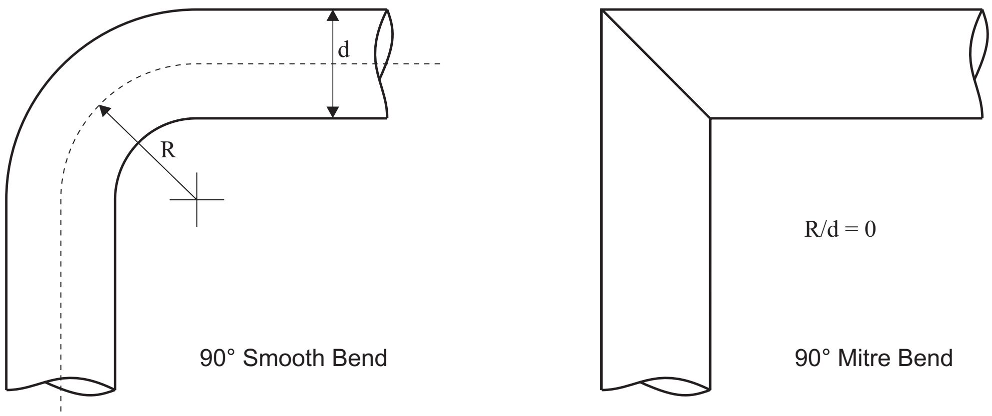


*Figure 14 Bend Radius and Pipe Diameter Relationship*

For tight bends such as mitres, the losses will be mainly due to flow separation and secondary flow patterns. For more gentle bends, flow separation and wall friction will predominate.

These losses can be represented with a loss factor, $k$.

$$h = ku^2/2g$$

However, it is helpful to differentiate between the total loss round the bend ($k_L$, $h_L$), and the loss due to bend geometry, ($k_B$, $h_B$) which ignores wall friction losses. The losses around the bend are created by the bend losses and an additional loss due to the length of pipe that it is made from. This additional loss must be added to $h_B$ to find $k_L$ and $h_L$. The loss due to bend geometry is found by measuring the head loss between the tappings and deducting the calculated head loss for an equivalent length of straight pipe.

In order to give good, steady manometer readings, the pressure tappings after the bends on the H408 are positioned downstream of the bends. The distance between tappings for each bend are given in Table 1.

(a) For each test point for each bend, calculate the flow velocity, and hence the Reynolds number.

(b) From the Reynolds number, calculate the frictional head loss for an equivalent length of smooth straight pipe using the Blasius equation. The head loss due to the bend geometry can now be found. For a more accurate measure of the frictional head loss, use the $k/d$ value from Experiment 1 to find the $f$ factor from the Moody chart, at the given Reynolds number.

(c) To determine the value of $k_B$ for each bend, plot the head loss due to bend geometry, $h_B$, against $u^2/2g$. The gradient of the line will be $k_B$.

(d) In order to see what effect the bend radius has on the energy loss, plot a graph of $k_B$ against $R/d$.

(e) If you were designing a piping system with 13.6 mm inside diameter pipe, and wanted to reduce the losses due to bends, what would you set as the minimum bend radius?

(f) Standard graphs of $k_L$ against $R/d$ show that $k_L$ has minimum value at $R/d$ of between 2 and 3 (see Figure 15). Why do you think this is?

(g) Which value $k_B$ or $k_L$ do you think is of most practical use and why?

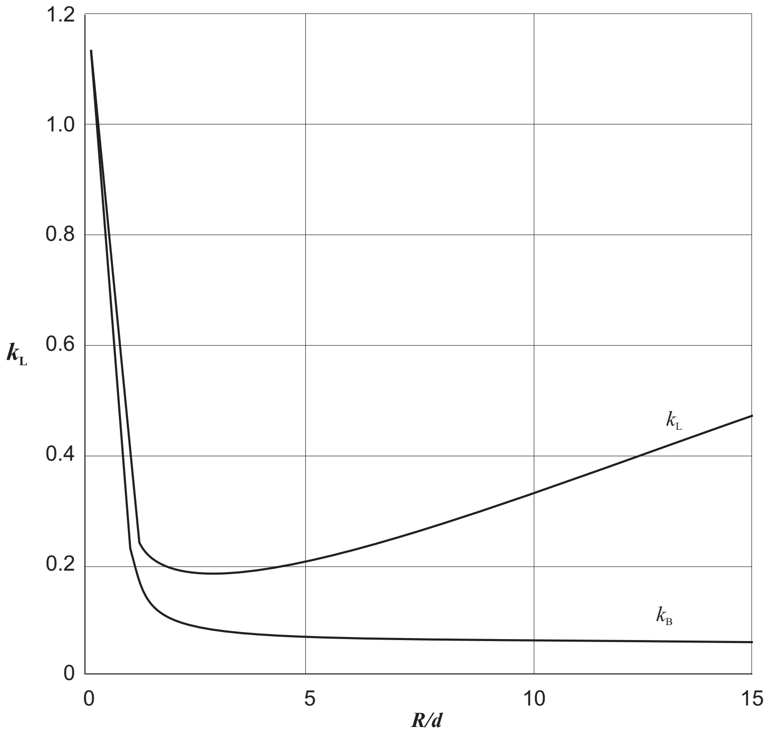


*Figure 15 Loss Coefficients for Smooth Bends*

## *4.6 Sudden Expansion and Sudden Contraction Experiments*

The Sudden Expansion and Sudden Contraction are on the same circuit and may be tested separately or at the same time (as in this experiment). For further investigation there is one more sudden contraction in one of the interchangeable sections, this must be tested separately.

### Aim

To determine the losses in a sudden expansion and a sudden contraction.

### Procedure

(1) Prepare blank tables similar to Table 4 (for the Sudden Expansion) and Table 5 (for the Sudden Contraction).

(2) Close the Gate valve and the Ball valve (dark blue and grey circuits). Open the Globe valve (light blue circuit) half of a turn.

(3) Turn on the cold water supply and wait for any trapped air to leave the circuit, then close the Globe valve.

(4) Connect one of the sets of piezometer tubes to the tappings at each side of the sudden expansion and a second set of piezometer tubes to the tappings at each side of the sudden contraction. If necessary, bleed the pipes as described in '**Setup**' on page 13.

(5) Use the hand pump if necessary to adjust the pressure in the Piezometer tubes until the levels are halfway up the scale. The level in each of the Piezometer tubes should be the same, if not then check for air bubbles or leaks.

(6) Fully open the Globe valve and wait for the flow to settle. Record the readings on the Piezometer into Table 4.

(7) Use the Globe valve to reduce the flow rate in five suitable steps to give a good spread of results.

| Sudden Expansion |
| --- |
| Area 1 ($A_1$): |
| Area 2 ($A_2$): |
| $d_2/d_1=$ |

| Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | Pressures | | | Velocities | | | $(u_1-u_2)^2/2g$ | $h_L$ (m) | $-(h_u-h_m)$ (m) |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $h_m$ (m) | Upstream $u_1$ ($m.s^{-1}$) | Downstream $u_2$ ($m.s^{-1}$) | Head Loss Due to Velocity Change $h_u$ (m) | | | |
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| | | | | | | | | | | |

*Table 4 Blank Results Table for Sudden Expansions*

| Sudden Contraction |
|---|
| Area 1 ($A_1$): |
| Area 2 ($A_2$): |
| $d_2/d_1$= |

| Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | Pressures | | | Velocities | | Head Loss Due to Velocity Change $h_u$ (m) | $h_L$ (m) | $h$ Total (m) | $h_m$-$h_u$ (m) | $u^2/2g$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $h_m$ (m) | Upstream $u_1$ ($m.s^{-1}$) | Downstream $u_2$ ($m.s^{-1}$) | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
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| | | | | | | | | | | | |

*Table 5 Blank Results Table for Sudden Contractions*

### Results Analysis

Unlike the other experiments, the sudden expansion and contractions cause a change in fluid velocity. This change in velocity affects the pressure head, and must be accounted for separately to the head loss due to the expansion/contraction itself. In fact, because the fluid is decelerating across the expansion, the static pressure rises.

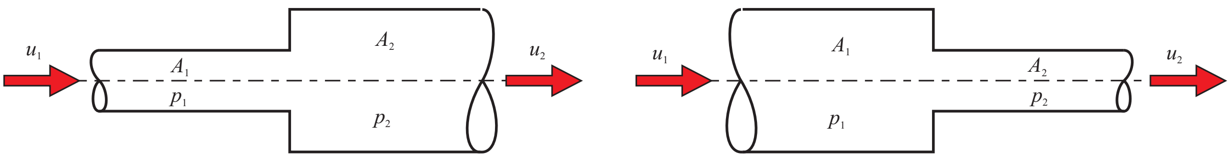


*Figure 16 Sudden Expansion and Sudden Contraction*

### Sudden Expansion

Head rise due to change in fluid velocity ($h_u$)

From Bernoulli's equation,

$$p_T = p_1 + ½\,\rho u_1^2 = p_2 + ½\,\rho u_2^2$$

And Continuity equation,

$$Q = A_1 u_1 = A_2 u_2$$

it can be shown that the head rise across the expansion is given by

$$h_u = h_2 - h_1 = u_1^2(1\text{-}(A_1/A_2)^2) \,/\, 2g$$

(a) For each flow rate, calculate the initial velocity, $u_1$, and hence the head rise due to velocity change across the expansion.

### Head Loss due to the Expansion ($h_L$)

Using Bernoulli's equation and the momentum equation, it can be shown that the head loss at a sudden expansion, $h_L$, is given as

$$h_L = k_L\,(u_1 - u_2)^2 \,/\, 2g$$

where $k_L$ is usually about 1.0.

(b) Calculate the head loss according to this equation.

The measured head change across the expansion will therefore be

$$h_1 - h_2 = h_L - h_u$$

This will have a negative value indicating that the head rises across the expansion.

(c) Calculate the head rise across the expansion.

(d) To verify the value of $k_L$, plot a graph of the head rise due to velocity minus the measured head rise, against

$(u_1 - u_2)^2 / 2g$, and the gradient will be the value of $k_L$. Determining the gradient of a graph is more accurate than using a single test point because it averages out any experimental scatter.

### Sudden Contraction

Head loss due to change in fluid velocity. $h_u$

From Bernoulli's equation,

$$p_T = p_1 + ½ \rho u_1^2 = p_2 + ½ \rho u_2^2$$

and the Continuity equation,

$$Q = A_1 u_1 = A_2 u_2$$

it can be shown that the head loss across the contraction is given by

$$h_u = h_1 - h_2 = u_2^2(1-(A_2/A_1)^2) / 2g$$

(a) For each flow rate, calculate the downstream velocity, $u_2$, using the continuity equation.

$$Q = A_2 u_2$$

and hence the head loss due to the velocity change across the contraction.

### Head Loss due to Contraction

Although a sudden contraction is geometrically the reverse of a sudden expansion, the same theory cannot be used in reverse because of differences in the flow patterns.

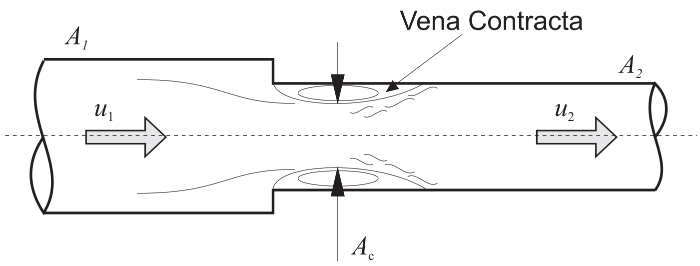


*Figure 17 The Vena Contracta*

The streamlines have to converge before the contraction, so they are not parallel through the actual contraction. The flow continues to converge slightly after the contraction to a smaller diameter than the narrow pipe (Vena Contracta) see Figure 17. Because of these factors, the flow analysis is based on previous experimentation.

The head loss due to the contraction itself, $h_L$, can be shown as

$$h_L = k_L u_2^2 / 2g$$

where the factor $k_L$ depends on the ratio of diameters (see Table 6).

| $d_2/d_1$ | $k$ |
|---|---|
| 0 | 0.50 |
| 0.2 | 0.45 |
| 0.4 | 0.38 |
| 0.6 | 0.28 |
| 0.8 | 0.14 |
| 1.0 | 0 |

*Table 6  Typical Values of the Coefficient k*

(b) $d_2/d_1$ = 0.52 for all expansions and contractions in the apparatus, so $k$ = 0.32. Use this value of $k$ to calculate the head loss due to the contraction.

(c) Calculate the combined head loss, $h_L + h_u$, and compare it to the measured head loss.

(d) The measured head loss can also be used to find the $k_L$ value for this contraction. Plot the measured head loss minus the head loss due to due to velocity change, $h_m - h_u$, against $u_2^2 / 2g$. The gradient of the line will be the constant $k_L$ for this contraction.

## 4.7 Losses In Valves and Strainer Experiments

### Aims

- To determine the losses in fully open valves and the in-line strainer.
- To determine the losses with valves at various openings

### Procedure 1 - Valves (fully open with variable flow)

(1) Prepare a table of results similar to Table 7.

(2) Fully open the Gate valve and close the other two valves.

(3) Turn on the cold water supply and wait for any trapped air to leave the circuit.

(4) Connect one of the sets of piezometer tubes to the tappings at each side of the valve. If necessary, bleed the pipes as described in **'Setup'** on page 13.

(5) Use the hand pump if necessary to adjust the pressure in the Piezometer tubes until the levels are halfway up the scale. The level in each of the Piezometer tubes should be the same, if not then check for air bubbles or leaks.

(6) Leave the valve fully open and reduce the water supply flow rate in five suitable steps to give a good spread of results. Record all readings into Table 7.

(7) Repeat for the other two valves.

| Item (Valve/Strainer):<br>Filter Type (if fitted): | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Pipe Diameter:**<br>**Pipe Area:** | | | | | | | | |
| **Time for 18 Litres (s)** | **Flow Rate ($Q$) ($m^3.s^{-1}$)** | **% Flow Rate** | **Piezometer/Gauge Readings*** | | | **Flow Velocity ($m.s^{-1}$)** | **$k$ Factor** | **Re** |
| | | | **Upstream Tapping (mm)** | **Downstream Tapping (mm)** | **Difference $\Delta h$ (m)** | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

*Table 7 Blank Results Table for the Valves and Strainer*

* To convert the pressure difference (in bars) indicated by the gauge to metres of water, multiply the gauge pressure by $10^5$ and divide this figure by 9810 (acceleration due to gravity x density of water).

### Procedure 2 - Strainer

(1) Prepare a table of results similar to Table 7.

(2) Connect up the interchangeable section that includes the strainer in the grey circuit.

(3) Unscrew the strainer and fit one of the filters supplied with the apparatus (see Figure 18).

(4) Open the Ball valve half a turn and close the other two valves.

(5) Turn on the cold water supply and wait for any trapped air to leave the circuit.

(6) Connect the strainer tapping connections to the pressure gauge. Bleed the pressure gauge as described in '**Setup**' on page 13.

(7) Fully open the Ball valve and wait for the flow to settle.

(8) Reduce the water supply flow rate in five suitable steps to give a good spread of results. Record all readings at each step.

(9) Repeat the experiment with the other filter.


*Figure 18 Unscrew Strainer to Fit Filter*

### Procedure 3 - Valves (variable opening)

For this test, the change in flow rate and head loss caused by the open or closed position of each of the valves is measured. The head loss will exceed the range of the piezometers at some point during the experiment, so the tappings must be transferred to the pressure gauge. Do not use the pressure gauge until this point, it is not as accurate as the piezometer at the low head loss ranges. Do not adjust the cold water supply flow rate during this experiment.

(1) Prepare a table of results similar to Table 8

(2) Carefully open and close the Gate valve. Count the amount of turns that the handwheel makes and convert each turn into a percentage figure. For example, if the handwheel turns five times, each turn represents a 20% change in valve opening (or closing), each quarter turn will be 5%.

(3) Open the Gate valve half a turn and close the other two valves.

(4) Turn on the cold water supply and wait for any trapped air to leave the circuit

(5) Connect one of the sets of piezometer tubes to the tappings at each side of the valve. If necessary, bleed the pipes as described in '**Setup**' on page 13.

(6) Fully open the Gate valve and record the head loss and flow rate.

(7) Carefully reduce the valve opening in increments as suggested in Table 8 and record the head loss and flow rate each time. Note that more readings are needed at small valve openings. When the head loss across the valve exceeds the range of the piezometer, transfer the tapping connections to the pressure gauge. Bleed the pressure gauge as described in '**Setup**' on page 13. For the low flow rates, use the measuring cylinder and stopwatch method.

(8) Repeat the experiment for the other two valves. Before using the Ball valve (grey circuit), fit the interchangeable section that includes the venturi and orifice.

| Valve Type: | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Valve Position | Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | Piezometer/Gauge Readings* | | | Flow Velocity $m.s^{-1}$ | $k$ Factor | Re |
| | | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $h$ (m) | | | |
| 100% (Fully Open) | | | | | | | | |
| 80% | | | | | | | | |
| 60% | | | | | | | | |
| 40% | | | | | | | | |
| 20% | | | | | | | | |
| 15% | | | | | | | | |
| 10% | | | | | | | | |
| 7.5% | | | | | | | | |
| 5% | | | | | | | | |
| 2.5% | | | | | | | | |
| 0% (Fully Closed) | | | | | | | | |

*Table 8  Blank Table of Results for Procedure 3*

* To convert the pressure difference (in bars) indicated by the gauge to metres of water, multiply the gauge pressure by $10^5$ and divide this figure by 9810 (acceleration due to gravity x density of water).

### Results Analysis

In pipe lines, there is usually some sort of valves fitted. Even when a valve is fully open, it causes additional losses, either because it presents a reduced area to the flow, or the flow has to follow a tortuous path though the valve. It is important to be able to find these losses when designing a system. The loss through a valve (or other pipe fitting) rises with the square of the flow speed. The head loss, $h$, can therefore be given as

$$h = ku^2/2g$$

where the value of $k$ will vary with the type of valve and the how open it is. Other fittings such as the in line strainer can be treated in exactly the same way.

(a) Use the continuity equation to calculate the flow velocity through the valve. To calculate the pipe area, the pipe inside diameter for each valve is 13.6 mm and for the strainer it is 17 mm.

$$Q = Au$$

(b) Use the velocity to calculate the $k$ value for each flow rate and valve setting for each valve.

(c) Which valves have the highest and lowest $k$ factors when fully open? Look at the cross sectional drawings of the valves and discuss why this is so.

(d) Is the $k$ value constant with flow rate, or does the speed affect $k$? It may be helpful to consider the Reynolds number.

(e) For the valve results at variable openings, calculate the flow rate as a percentage of the maximum flow rate. Plot the $k$ factor against percentage flow rate for all the valves.

(f) For the strainer or other fixed dimension items, plot the $k$ factor against the Reynolds number.

(g) Plot the Head loss against Flow rate for the Strainer.

(h) Which type of valve would you choose to control the flow rate close to the maximum? Which type of valve would you choose to control the flow rate at low rates?

Table 9 gives some typical values of $k$ for valves. Note that the values are based on valves designed for 13.6 mm internal diameter pipe fittings.

| Valve type | $k$ |
|---|---|
| Globe valve, fully open | 10.0 |
| Gate valve, fully open | 0.12 |
| Gate valve, 75% open | 1.0 |
| Gate valve, half open | 6.0 |
| Gate valve, 25% open | 24.0 |
| Ball valve, fully open | 0.08 |

*Table 9 Typical Head Losses in Valves*

### *4.8 Flow Measurement Experiments*

**Aim**

To show how flow may be measured by an Orifice, a Venturi or a Pitot tube

**Procedure 1 - Orifice and Venturi Meters**

(1) Prepare a blank table of results similar to Table 10.

(2) Connect the interchangeable section that includes the Orifice, Venturi and Pitot Assembly.

(3) Open the Ball valve half a turn and close the other two valves.

(4) Turn on the cold water supply and wait for any trapped air to leave the circuit. Check the clear down-tube for signs of trapped air. To move stubborn pockets of air, quickly open and close the Ball valve several times. Close the Ball valve.

(5) Connect one of the sets of piezometer tubes to the tappings at each side of the Venturi. Connect a second set of piezometer tubes to the tappings at each side of the Orifice. If necessary, bleed the pipes as described in **'Setup'** on page 13.

(6) Use the hand pump if necessary to adjust the pressure in the Piezometer tubes until the levels are halfway up the scale. The level in each of the Piezometer tubes should be the same, if not then check for air bubbles or leaks.

(7) Fully open the ball valve, wait for the flow to settle and record the readings for the Orifice and Venturi.

(8) Close the Ball valve in five equal steps, record the readings for the Orifice and Venturi each time.

| Time for 18 Litres (s) | Flow Rate ($Q$) ($L.s^{-1}$) | Orifice Readings | | | Venturi Readings | | |
|---|---|---|---|---|---|---|---|
| | | Tapping 25 (mm) | Tapping 24 (mm) | Difference (Head Loss) $h$ (m) | Tapping 29 (mm) | Tapping 28 (mm) | Difference (Head Loss) $h$ (m) |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

*Table 10 Blank Table of Results For Orifice and Venturi Meter Procedure*

### Procedure 2 - Velocity Profile

(1) Prepare a table of results similar to Table 11

(2) Make sure that the Pitot Assembly is set as shown in '**To Fit the Pitot Traverse Assembly**' on page 9.

(3) Connect the interchangeable section that includes the Orifice, Venturi and Pitot Assembly.

(4) Open the Ball valve half a turn and close the other two valves.

(5) Turn on the cold water supply and wait for any trapped air to leave the circuit. Check the clear down tube for signs of trapped air. To move stubborn pockets of air, quickly open and close the Ball valve several times. Close the Ball valve.

(6) Connect one of the sets of piezometer tubes to the tappings on the Pitot Assembly. If necessary, bleed the pipes as described in '**Setup**' on page 13.

(7) Use the hand pump if necessary to adjust the pressure in the Piezometer tubes until the levels are halfway up the scale. The level in each of the Piezometer tubes should be the same, if not then check for air bubbles or leaks.

(8) Fully open the ball valve, wait for the flow to settle and record the flow and the head loss readings for the Orifice and Venturi.

(9) Use the micrometer on the Pitot Assembly to set the Pitot tube to the centre of the pipe (10.925 mm) and take readings of the difference between Static Pressure and Pitot Pressure.

(10) Move the micrometer in steps as suggested in Table 11. Wait at least one minute between each step, to allow conditions around the pitot to stabilize and record the readings.

(11) Repeat the experiment at other flow rates. Try to achieve the same flow rates as in Procedure 1, so that the results can be compared.

| **Pitot Position (mm)** | **Radius from pipe centre (mm)** | **Radius$^2$** $r^2$ **($m^2$)** | **Pressure Difference** $\Delta h$ **(mm water)** | **Flow Velocity** $u$ $(\sqrt{2g\Delta h})$ **($m.s^{-1}$)** | **Simpsons Rule** **($\Delta r$ x $\Delta u/2$)** |
|---|---|---|---|---|---|
| 10.925 | 0 | 0 | | | |
| 8.925 | 2 | $40 \times 10^{-6}$ | | | |
| 6.925 | 4 | $1.60 \times 10^{-5}$ | | | |
| 4.925 | 6 | $3.60 \times 10^{-5}$ | | | |
| 2.925 | 8 | $6.40 \times 10^{-5}$ | | | |
| 2.425 | 8.5 | $7.23 \times 10^{-5}$ | | | |
| 1.925 | 9 | $8.10 \times 10^{-5}$ | | | |
| 1.425 | 9.5 | $9.03 \times 10^{-5}$ | | | |
| 0.925 | 10 | $1.0 \times 10^{-4}$ | | | |
| | Theoretical Maximum Radius = 10.925 | Theoretical Maximum Radius$^2$ = $1.19 \times 10^{-4}$ | | Theoretical Velocity at Maximum Radius = 0 | Flow rate = (sum of this column) |

*Table 11 Blank Table of Results for Velocity Profile Procedure*

## Results Analysis

### Orifice Meter

Using Bernoulli's equation and Continuity Equation it can be shown that the flow through an Orifice is given by:

$$Q = C_d A_1 \left\{ \frac{2g(h_1 - h_2)}{(A_1^2 / A_2^2) - 1} \right\}^{1/2}$$

The coefficient of discharge $C_d$ is calculated from the dimensions of the orifice. This is simplified as the orifice is designed to BS1042:1981.

For this orifice, the dimensions are:

| | |
|---|---|
| $C_d$ | 0.601 |
| $d_1$ | 51.9 mm |
| $d_2$ | 20.0 mm |
| $A_1$ | 2.116 x $10^{-3}$ $m^2$ |
| $A_2$ | 3.142 x $10^{-4}$ $m^2$ |

*Table 12 Dimensions of the Orifice*

As an example, with a flow rate of 0.31 $kg.s^{-1}$ (gravimetric flow rate measured on the H1), Tapping 25 = 762 mm and Tapping 24 = 630 mm,

$$= 0.601 \times (2.116 \times 10^{-3}) \left\{ \frac{2 \times 9.81(0.762 - 0.630)}{\frac{(2.116 \times 10^{-3})^2}{(3.142 \times 10^{-4})^2} - 1} \right\}^{\frac{1}{2}}$$

Gives Q = 0.307 $kg.s^{-1}$ (gravimetric or mass flow)

or Q = 3.07 x $10^{-4} m^3.s^{-1}$ (volumetric flow rate)

### Venturi Meter

The same analysis can be applied to the Venturi.

The dimensions for the Venturi are shown in Table 13.

| | |
|---|---|
| $C_d$ | 0.96 |
| $d_1$ | 26.0 mm |
| $d_2$ | 16.0 mm |
| $A_1$ | 5.309 x $10^{-4}$ $m^2$ |
| $A_2$ | 2.011 x $10^{-4}$ $m^2$ |

*Table 13 Dimensions for the Venturi*

As an example, with the same flow rate as for the Orifice example, 0.31 kg.$s^{-1}$ (gravimetric flow measured by the H1), Tapping 29 = 758 mm and Tapping 28 = 642 mm,

$$= 0.96 \times (5.309 \times 10^{-4}) \left\{ \frac{2 \times 9.81(0.758 - 0.642)}{\dfrac{(5.309 \times 10^{-4})^2}{(2.011 \times 10^{-4})^2} - 1} \right\}^{\frac{1}{2}}$$

Gives Q = 0.315 kg.$s^{-1}$ (gravimetric or mass flow rate)

or Q = 3.15 x $10^{-4}m^3.s^{-1}$ (volumetric flow rate)

(a) Compare the Venturi and the Orifice, which flow meter restricts the flow more? Why do you think you might use an orifice rather than a Venturi meter?

**Pitot Tube**

The velocity profile across the pipe can be investigated using the traversing pitot tube. The pitot can travel across the full diameter of the pipe, measuring the total pressure. A static tapping is also provided, exactly in line with the head of the pitot. The pressure differential between the total and static measurements is therefore the dynamic pressure, from which the fluid velocity can be established. Rearranging Bernoulli's equation gives:

$$u = \sqrt{2g\Delta h}$$

The volumetric flow rate is the product of the velocity and the area. As the area of circle increases with the square of the radius, plot the velocity against radius squared, and the area under the graph will be the flow rate. The area under the graph can be measured from the graph, or calculated using Simpson's rule, where the average of two adjacent velocity readings are multiplied by the change in radius squared, shown in the example table of results. The fluid velocity immediately adjacent to the wall will be zero. In the example shown, the velocity is plotted from the centre to wall of the pipe, so the flow rate is twice the area under the graph.

In the example, the area under the graph is 3.13 x $10^{-4}m^3.s^{-1}$, or 0.313 kg.$s^{-1}$, which is very comparable to the flow rate of 0.31 kg.$s^{-1}$ measured by the H1 gravimetric bench used for the test.

## SECTION 5.0 SAMPLE RESULTS

**Please Note: The following results are for reference only. Actual results may differ slightly.**

### *5.1 Losses in Straight Pipes Experiments*

| Internal Diameter ($d$) = 0.0136 m | | | Area ($A$) = 0.0001453 $m^2$ | | Length ($l$) = 0.912 m | | | |
|---|---|---|---|---|---|---|---|---|
| Pipe Type (Smooth/Rough) = 13.6 mm Smooth Straight Pipe | | | | | | | | |
| **Time for 18 Litres (s)** | **Flow Rate ($Q$) ($m^3.s^{-1}$)** | **Piezometer Readings** | | | **Flow Velocity ($m.s^{-1}$)** | **Re** | $f$ | **Blasius** $f$ |
| | | **Upstream Tapping (mm)** | **Downstream Tapping (mm)** | **Difference ($\Delta h$) (m)** | | | | |
| 72.6 | 0.000248 | 1044 | 780 | 0.264 | 1.707 | $2.31 \times 10^4$ | 0.0066 | 0.0067 |
| 80 | 0.000225 | 1010 | 785 | 0.225 | 1.549 | $2.10 \times 10^4$ | 0.0069 | 0.0069 |
| 105 | 0.000171 | 923 | 777 | 0.146 | 1.180 | $1.60 \times 10^4$ | 0.0077 | 0.0074 |
| 142 | 0.000127 | 848 | 763 | 0.085 | 0.873 | $1.18 \times 10^4$ | 0.0082 | 0.0080 |
| 198 | 0.000091 | 802 | 755 | 0.047 | 0.626 | $8.48 \times 10^3$ | 0.0088 | 0.0087 |
| | | | | | | | | |

*Table 14 Results for 13.6 mm Smooth Straight Pipe*

| Internal Diameter ($d$) = 0.0262 m | | | Area ($A$) = 0.0005391 $m^2$ | | Length ($l$) = 0.912 m | | | |
|---|---|---|---|---|---|---|---|---|
| Pipe Type (Smooth/Rough) = 26.2 mm Smooth Straight Pipe | | | | | | | | |
| **Time for 18 Litres (s)** | **Flow Rate ($Q$) ($m^3.s^{-1}$)** | **Piezometer Readings** | | | **Flow Velocity ($m.s^{-1}$)** | **Re** | $f$ | **Blasius** $f$ |
| | | **Upstream Tapping (mm)** | **Downstream Tapping (mm)** | **Difference ($\Delta h$) (m)** | | | | |
| 71 | 0.000254 | 948 | 934 | 0.014 | 0.470 | $1.23 \times 10^4$ | 0.0089 | 0.0075 |
| 74 | 0.000243 | 932 | 922 | 0.010 | 0.451 | $1.18 \times 10^4$ | 0.0069 | 0.0076 |
| 82 | 0.000220 | 910 | 900 | 0.010 | 0.407 | $1.06 \times 10^4$ | 0.0085 | 0.0078 |
| 103 | 0.000175 | 882 | 874 | 0.008 | 0.324 | $8.46 \times 10^4$ | 0.0107 | 0.0082 |
| | | | | | | | | |

*Table 15 Results for 26.2 mm Smooth Straight Pipe*

| Internal Diameter ($d$) = 0.017 m | Area ($A$) = 0.000227 m$^2$ | Length ($l$) = 0.912 m |
|---|---|---|
| Pipe Type (Smooth/Rough) = 17 mm Smooth Straight Pipe | | |

| Time for 18 Litres (s) | Flow Rate ($Q$) (m$^3$.s$^{-1}$) | Piezometer Readings | | | Flow Velocity (m.s$^{-1}$) | Re | $f$ | Blasius $f$ |
|---|---|---|---|---|---|---|---|---|
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference ($\Delta h$) (m) | | | | |
| 60 | 0.000300 | 977 | 867 | 0.11 | 1.322 | $2.24 \times 10^4$ | 0.0058 | 0.0065 |
| 65 | 0.000277 | 954 | 853 | 0.101 | 1.220 | $2.07 \times 10^4$ | 0.0062 | 0.0066 |
| 71 | 0.000254 | 930 | 842 | 0.088 | 1.117 | $1.89 \times 10^4$ | 0.0064 | 0.0067 |
| 93 | 0.000194 | 869 | 813 | 0.056 | 0.853 | $1.44 \times 10^4$ | 0.0070 | 0.0072 |
| 155 | 0.000116 | 804 | 779 | 0.025 | 0.512 | $8.66 \times 10^3$ | 0.0087 | 0.0082 |
| 675 | 0.000027 | 783 | 774 | 0.009 | 0.117 | $1.99 \times 10^3$ | na | na |

*Table 16 Results for 17 mm Smooth Straight Pipe*

| Internal Diameter ($d$) = 0.004 m | Area ($A$) = 0.00001257 m$^2$ | Length ($l$) = 0.35 m |
|---|---|---|
| Pipe Type (Smooth/Rough) = 4 mm Smooth Straight Pipe | | |

| Time for 1 Litre (s) | Flow Rate ($Q$) (m$^3$.s$^{-1}$) | Piezometer Readings | | | Flow Velocity (m.s$^{-1}$) | Re | $f$ | Blasius $f$ |
|---|---|---|---|---|---|---|---|---|
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference ($\Delta h$) (m) | | | | |
| 31.5 | 0.000032 | 1038 | 2 | 1.036 | 2.526 | $1.01 \times 10^4$ | 0.0091 | 0.0079 |
| 37.5 | 0.000027 | 910 | 155 | 0.755 | 2.122 | $8.45 \times 10^4$ | 0.0094 | 0.0082 |
| 44.7 | 0.000022 | 831 | 280 | 0.551 | 1.780 | $7.09 \times 10^4$ | 0.0097 | 0.0086 |
| 57.7 | 0.000017 | 755 | 393 | 0.362 | 1.379 | $5.49 \times 10^4$ | 0.0107 | 0.0092 |
| 101 | 0.000010 | 660 | 534 | 0.126 | 0.788 | $3.14 \times 10^3$ | 0.0114 | 0.0106 |
| | | | | | | | | |

*Table 17 Results for 4 mm Smooth Straight Pipe*

| Internal Diameter ($d$) = 0.014 m | Area ($A$) = 0.0001539 m$^2$ | Length ($l$) = 0.2 m |
|---|---|---|
| Pipe Type (Smooth/Rough) = 17mm (14 mm) Rough Straight Pipe | | |

| Time for 18 Litres (s) | Flow Rate ($Q$) (m$^3$.s$^{-1}$) | Piezometer Readings | | | Flow Velocity (m.s$^{-1}$) | Re | $f$ | Blasius $f$ |
|---|---|---|---|---|---|---|---|---|
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference ($\Delta h$) (m) | | | | |
| 64 | 0.000281 | 862 | 708 | 0.154 | 1.827 | $2.55 \times 10^4$ | 0.0158 | 0.0063 |
| 66 | 0.000273 | 865 | 735 | 0.130 | 1.772 | $2.47 \times 10^4$ | 0.0142 | 0.0063 |
| 78 | 0.000231 | 883 | 789 | 0.094 | 1.499 | $2.09 \times 10^4$ | 0.0144 | 0.0066 |
| 111 | 0.000162 | 903 | 848 | 0.055 | 1.053 | $1.47 \times 10^4$ | 0.0170 | 0.0072 |
| 132 | 0.000136 | 904 | 864 | 0.040 | 0.886 | $1.24 \times 10^4$ | 0.0175 | 0.0075 |
| 246 | 0.000073 | 910 | 897 | 0.013 | 0.475 | $6.63 \times 10^3$ | 0.0198 | 0.0088 |

*Table 18 Results for 17 mm Rough Pipe*

## 5.2 Losses in Bends Experiments

Internal Diameter ($d$) = 0.0136 m | Pipe Length ($l$) = 0.652 m

Bend Radius ($R$) = 150 mm (0.15 m)

| Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | Piezometer Readings | | | Flow Velocity ($m.s^{-1}$) | Re | Blasius $f$ | Straight Pipe Loss | Bend Loss | $u^2/2g$ | $k_L$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference ($\Delta h$) (m) | | | | | | | |
| 70 | 0.000257 | 948 | 725 | 0.223 | 1.770 | $2.40 \times 10^4$ | 0.0067 | 0.204 | 0.019 | 0.160 | 0.117269 |
| 86 | 0.000209 | 886 | 732 | 0.154 | 1.441 | $1.95 \times 10^4$ | 0.0070 | 0.142 | 0.012 | 0.106 | 0.108866 |
| 92 | 0.000196 | 869 | 733 | 0.136 | 1.347 | $1.82 \times 10^4$ | 0.0071 | 0.127 | 0.009 | 0.092 | 0.101457 |
| 120 | 0.000150 | 822 | 735 | 0.087 | 1.033 | $1.40 \times 10^4$ | 0.0076 | 0.080 | 0.007 | 0.054 | 0.137352 |
| 185 | 0.000097 | 778 | 740 | 0.038 | 0.670 | $9.07 \times 10^3$ | 0.0085 | 0.037 | 0.001 | 0.023 | 0.031101 |
| 245 | 0.000073 | 765 | 741 | 0.024 | 0.506 | $6.85 \times 10^3$ | 0.0091 | 0.023 | 0.001 | 0.013 | 0.091424 |

Internal Diameter ($d$) = 0.0136 m | Pipe Length ($l$) = 0.864 m

Bend Radius ($R$) = 100 mm (0.1 m)

| Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | Piezometer Readings | | | Flow Velocity ($m.s^{-1}$) | Re | Blasius $f$ | Straight Pipe Loss | Bend Loss | $u^2/2g$ | $k_L$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference ($\Delta h$) (m) | | | | | | | |
| 70 | 0.000257 | 763 | 470 | 0.293 | 1.770 | $2.40 \times 10^4$ | 0.0067 | 0.271 | 0.022 | 0.160 | 0.139688 |
| 86 | 0.000209 | 687 | 476 | 0.211 | 1.441 | $1.95 \times 10^4$ | 0.0070 | 0.189 | 0.022 | 0.106 | 0.209727 |
| 92 | 0.000196 | 661 | 476 | 0.185 | 1.347 | $1.82 \times 10^4$ | 0.0071 | 0.168 | 0.017 | 0.092 | 0.186137 |
| 120 | 0.000150 | 598 | 478 | 0.12 | 1.033 | $1.40 \times 10^4$ | 0.0076 | 0.105 | 0.015 | 0.054 | 0.268714 |
| 185 | 0.000097 | 521 | 479 | 0.042 | 0.670 | $9.07 \times 10^3$ | 0.0085 | 0.049 | - 0.007 | 0.023 | -0.32423 |
| 245 | 0.000073 | 511 | 480 | 0.031 | 0.506 | $6.85 \times 10^3$ | 0.0091 | 0.030 | 0.001 | 0.013 | 0.059504 |

*Table 19 Results for 150 mm and 100 mm Radius Bend*

| Internal Diameter ($d$) = 0.0136 m | | Pipe Length ($l$) = 0.919 m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bend Radius ($R$) = N/A Elbow | | | | | | | | | | | |
| Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | Piezometer Readings | | | Flow Velocity ($m.s^{-1}$) | Re | Blasius $f$ | Straight Pipe Loss | Bend Loss | $u^2/2g$ | $k_L$ |
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference ($\Delta h$) (m) | | | | | | | |
| 73.5 | 0.000245 | 1007 | 632 | 0.375 | 1.686 | $2.28 \times 10^4$ | 0.0068 | 0.264 | 0.111 | 0.145 | 0.763797 |
| 80 | 0.000225 | 982 | 643 | 0.339 | 1.549 | $2.10 \times 10^4$ | 0.0069 | 0.228 | 0.111 | 0.122 | 0.908425 |
| 105 | 0.000171 | 882 | 688 | 0.194 | 1.180 | $1.60 \times 10^4$ | 0.0074 | 0.142 | 0.052 | 0.071 | 0.737998 |
| 130 | 0.000138 | 840 | 706 | 0.134 | 0.953 | $1.29 \times 10^4$ | 0.0078 | 0.097 | 0.037 | 0.046 | 0.789266 |
| 186 | 0.000097 | 795 | 723 | 0.072 | 0.666 | $9.02 \times 10^3$ | 0.0085 | 0.052 | 0.020 | 0.023 | 0.881293 |
| 282 | 0.000064 | 766 | 735 | 0.031 | 0.439 | $5.95 \times 10^3$ | 0.0094 | 0.025 | 0.006 | 0.010 | 0.596113 |

| Internal Diameter ($d$) = 0.0136 m | | Pipe Length ($l$) = 0.92 m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bend Radius ($R$) = 50 mm (0.05 m) | | | | | | | | | | | |
| Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | Piezometer Readings | | | Flow Velocity ($m.s^{-1}$) | Re | Blasius $f$ | Straight Pipe Loss | Bend Loss | $u^2/2g$ | $k_L$ |
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference ($\Delta h$) (m) | | | | | | | |
| 70 | 0.000257 | 880 | 570 | 0.31 | 1.770 | 2.40E+04 | 0.0067 | 0.288 | 0.022 | 0.160 | 0.1362762 |
| 86 | 0.000209 | 834 | 615 | 0.219 | 1.441 | 1.95E+04 | 0.0070 | 0.201 | 0.018 | 0.106 | 0.1696761 |
| 92 | 0.000196 | 822 | 628 | 0.194 | 1.347 | 1.82E+04 | 0.0071 | 0.179 | 0.015 | 0.092 | 0.1658541 |
| 120 | 0.000150 | 786 | 664 | 0.122 | 1.033 | 1.40E+04 | 0.0076 | 0.112 | 0.010 | 0.054 | 0.1798108 |
| 185 | 0.000097 | 753 | 697 | 0.056 | 0.670 | 9.07E+03 | 0.0085 | 0.053 | 0.003 | 0.023 | 0.1479912 |
| 245 | 0.000073 | 741 | 708 | 0.033 | 0.506 | 6.85E+03 | 0.0091 | 0.032 | 0.001 | 0.013 | 0.062651 |

*Table 20 Results for 50 mm Bend and Elbow*

| Item | $r/D$ | $k$ (Excluding Friction) | $k$ (Including Friction) |
|---|---|---|---|
| 150 Radius Bend | 11.03 | 0.1128 | 0.5923 |
| 100 Radius Bend | 7.35 | 0.1363 | 0.4861 |
| 50 Radius Bend | 3.77 | 0.1664 | 0.2904 |
| Elbow | 1 | 0.8125 | 0.8562 |
| Mitre | 0 | 1.4631 | 1.4631 |

| Internal Diameter ($d$) = 0.0136 m | | Pipe Length ($l$) = 0.94 m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bend Radius ($R$) = N/A Mitre Bend | | | | | | | | | | | |
| Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | Piezometer Readings | | | Flow Velocity ($m.s^{-1}$) | Re | Blasius $f$ | Straight Pipe Loss | Bend Loss | $u^2/2g$ | $k_L$ |
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference ($\Delta h$) (m) | | | | | | | |
| 73.5 | 0.000245 | 869 | 396 | 0.473 | 1.686 | $2.28 \times 10^4$ | 0.0068 | 0.270 | 0.203 | 0.145 | 1.39863 |
| 80 | 0.000225 | 833 | 408 | 0.425 | 1.549 | $2.10 \times 10^4$ | 0.0069 | 0.233 | 0.192 | 0.122 | 1.569174 |
| 105 | 0.000171 | 687 | 444 | 0.243 | 1.180 | $1.60 \times 10^4$ | 0.0074 | 0.145 | 0.098 | 0.071 | 1.382748 |
| 130 | 0.000138 | 625 | 458 | 0.167 | 0.953 | $1.29 \times 10^4$ | 0.0078 | 0.100 | 0.067 | 0.046 | 1.453846 |
| 186 | 0.000097 | 559 | 469 | 0.09 | 0.666 | $9.02 \times 10^3$ | 0.0085 | 0.053 | 0.037 | 0.023 | 1.624465 |
| 282 | 0.000064 | 527 | 476 | 0.051 | 0.439 | $5.95 \times 10^3$ | 0.0094 | 0.026 | 0.025 | 0.010 | 2.570187 |

*Table 21 Results for Mitre and R/d for all bends*

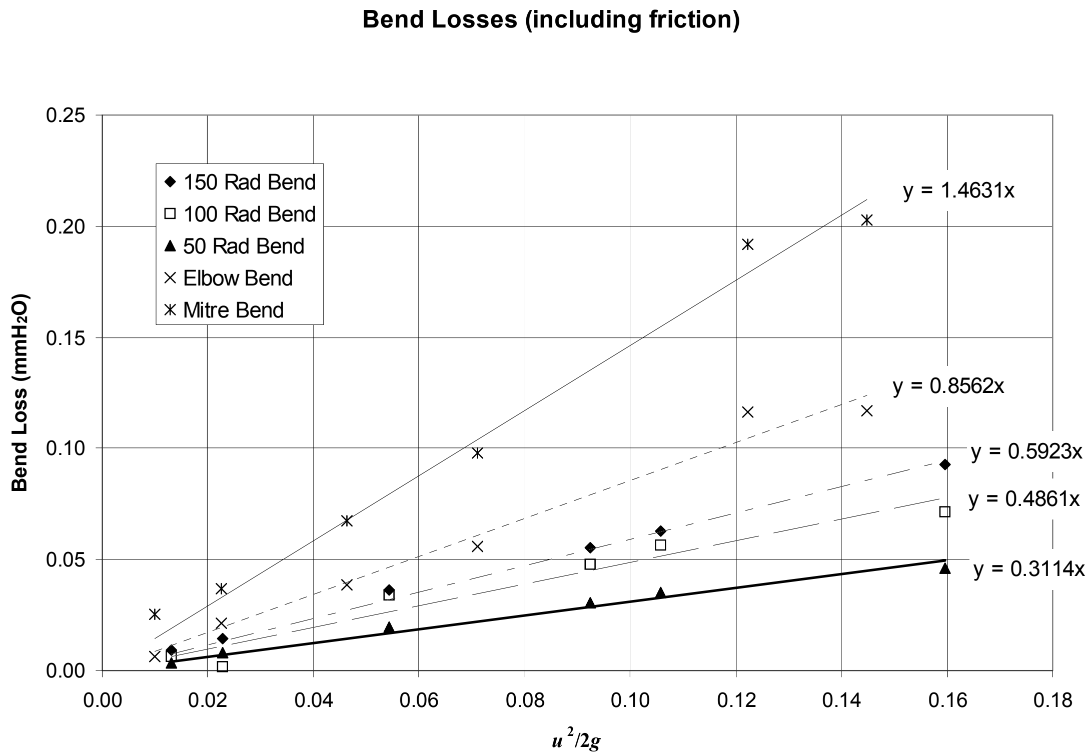


*Figure 19 Results for all Bends*

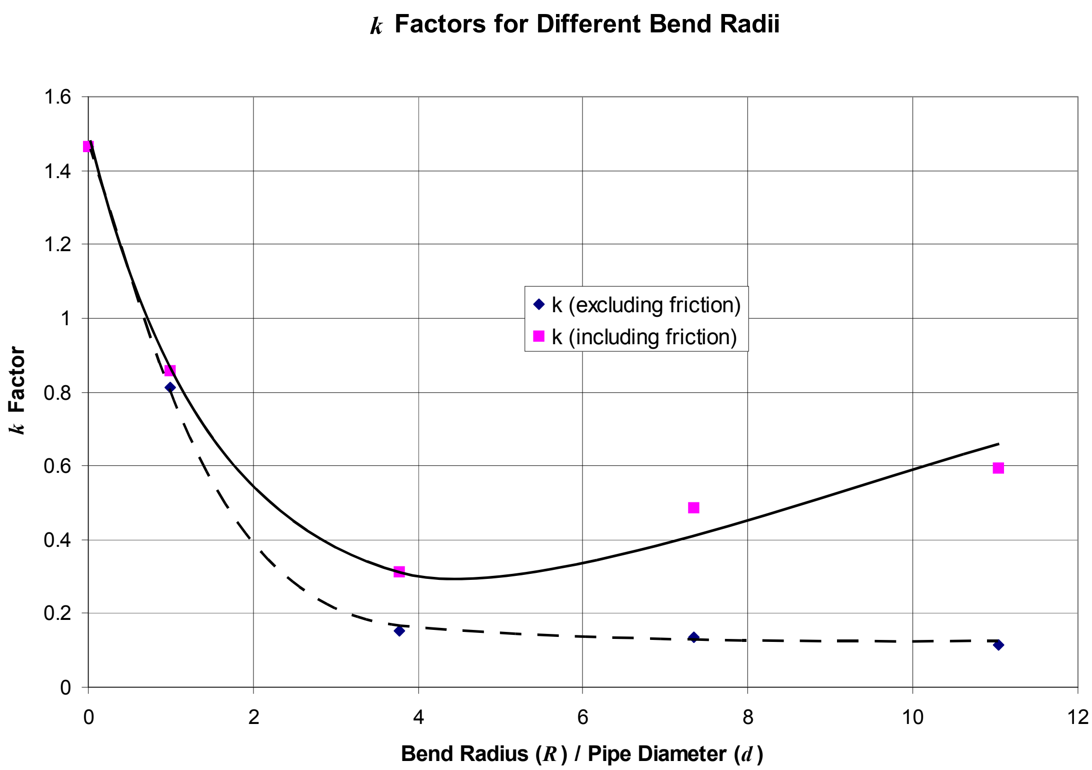


*Figure 20 $k$ Factors*

## 5.3 Sudden Expansion and Contraction Experiments

| Sudden Expansion | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Area 1 ($A_1$): 0.000145267 m$^2$ | | | | | | | | | | |
| Area 2 ($A_2$): 0.000539129 m$^2$ | | | | | | | | | | |
| $d_2/d_1$= 0.519083969 | | | | | | | | | | |
| Time for 18 Litres (s) | Flow Rate ($Q$) (m$^3$.s$^{-1}$) | Pressures | | | Velocities | | | $(u_1\text{-}u_2)^2/2g$ | $h_L$ (m) | $-(h_u\text{-}h_m)$ (m) |
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $h_m$ (m) | Upstream $u_1$ (m.s$^{-1}$) | Downstream $u_2$ (m.s$^{-1}$) | Head Loss Due to Velocity Change $h_u$ (m) | | | |
| 69 | 0.000261 | 704 | 761 | -0.057 | 1.796 | 0.484 | -0.152 | 0.0877 | -0.0647 | 0.095 |
| 76 | 0.000237 | 684 | 733 | -0.049 | 1.630 | 0.439 | -0.126 | 0.0723 | -0.0533 | 0.077 |
| 88 | 0.00205 | 642 | 677 | -0.035 | 1.408 | 0.379 | -0.094 | 0.0539 | -0.0398 | 0.059 |
| 115 | 0.000157 | 589 | 609 | -0.020 | 1.077 | 0.290 | -0.055 | 0.0316 | -0.0233 | 0.035 |
| 139 | 0.000129 | 560 | 573 | -0.013 | 0.891 | 0.240 | -0.038 | 0.0216 | -0.0159 | 0.025 |
| 233 | 0.000077 | 513 | 519 | -0.006 | 0.532 | 0.143 | -0.013 | 0.0077 | -0.0057 | 0.007 |

*Table 22 Results for the Sudden Expansion*

| Sudden Contraction |
|---|
| Area 1 ($A_1$): 0.00539129 m$^2$ |
| Area 2 ($A_2$): 0.000145267 m$^2$ |
| $d_2/d_1$= 0.519083969 |

| Time for 18 Litres (s) | Flow Rate ($Q$) (m$^3$.s$^{-1}$) | Pressures | | | Velocities | | Head Loss Due to Velocity Change $h_u$ (m) | $h_L$ (m) | $h$ Total (m) | $h_m$-$h_u$ (m) | $u^2/2g$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $h_m$ (m) | Upstream $u_1$ (m.s$^{-1}$) | Downstream $u_2$ (m.s$^{-1}$) | | | | | |
| 69 | 0.000261 | 1044 | 802 | 0.242 | 0.484 | 1.796 | 0.152 | 0.053 | 0.205 | 0.090 | 0.1643662 |
| 76 | 0.000237 | 1023 | 799 | 0.224 | 0.439 | 1.630 | 0.126 | 0.043 | 0.169 | 0.098 | 0.1354826 |
| 88 | 0.000205 | 954 | 793 | 0.161 | 0.379 | 1.408 | 0.094 | 0.032 | 0.126 | 0.067 | 0.1010521 |
| 115 | 0.000157 | 877 | 782 | 0.095 | 0.290 | 1.077 | 0.055 | 0.019 | 0.074 | 0.040 | 0.0591718 |
| 139 | 0.000129 | 839 | 773 | 0.066 | 0.240 | 0.891 | 0.038 | 0.013 | 0.051 | 0.028 | 0.0405024 |
| 233 | 0.000077 | 781 | 757 | 0.024 | 0.143 | 0.532 | 0.013 | 0.005 | 0.018 | 0.011 | 0.0144145 |

*Table 23  Results for the Sudden Contraction*

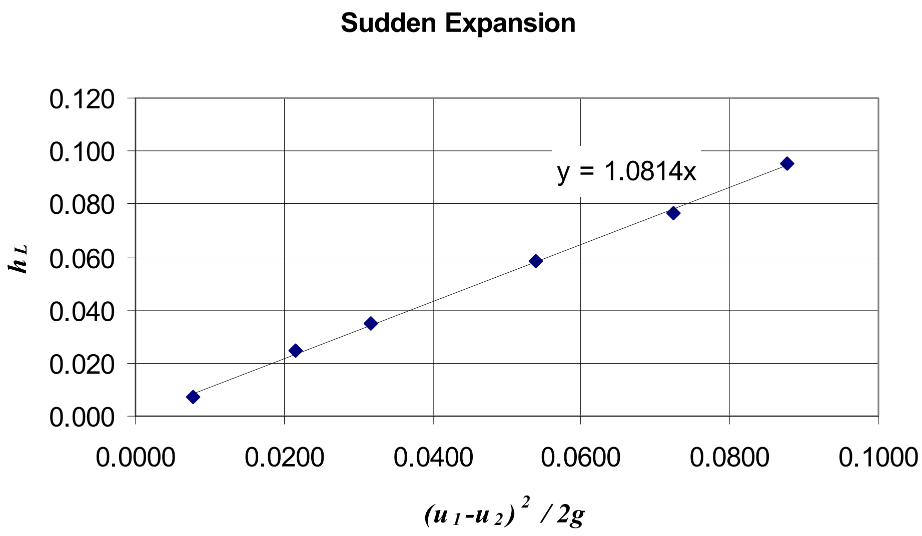


*Figure 21 Graph for Sudden Expansion*

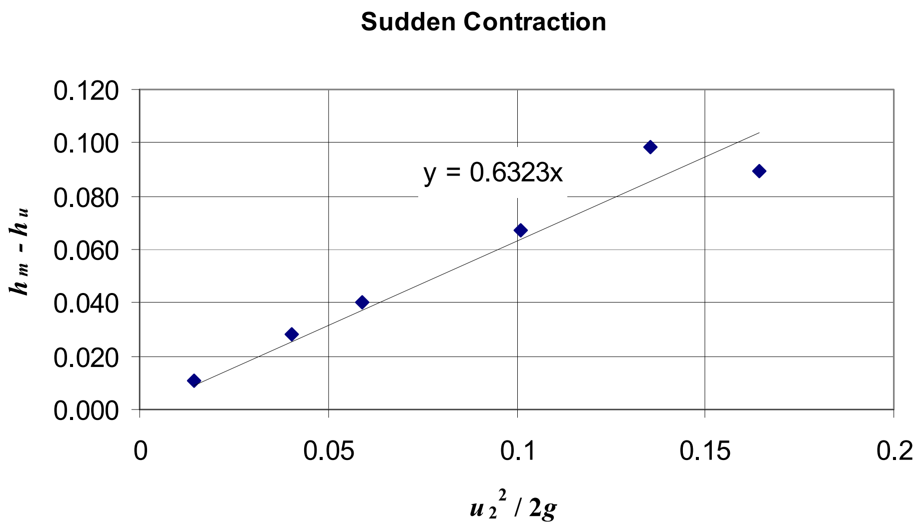


*Figure 22 Graph for Sudden Contraction*

## 5.4 Losses in Valves and Strainer Experiments

### Fully Open Valves

**Item (Valve/Strainer): Gate Valve**
**Filter Type (if fitted):**

**Pipe Diameter: 0.0136 m**
**Pipe Area: 0.000145267 m$^2$**

| Time for 18 Litres (s) | Flow Rate ($Q$) (m$^3$.s$^{-1}$) | Piezometer/Gauge Readings | | | Flow Velocity (m.s$^{-1}$) | $k$ Factor | Re |
|---|---|---|---|---|---|---|---|
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $\Delta h$ (m) | | | |
| 73 | 0.000247 | 671 | 477 | 0.194 | 1.697 | 1.3211 | $2.46 \times 10^4$ |
| 78 | 0.000231 | 664 | 494 | 0.170 | 1.589 | 1.3217 | $2.30 \times 10^4$ |
| 94 | 0.000191 | 611 | 494 | 0.117 | 1.318 | 1.3211 | $1.91 \times 10^4$ |
| 114 | 0.000158 | 584 | 500 | 0.084 | 1.087 | 1.3950 | $1.57 \times 10^4$ |
| 228 | 0.000079 | 535 | 511 | 0.024 | 0.543 | 1.5943 | $7.86 \times 10^3$ |

*Table 24 Results for Fully Open Gate Valve*

**Item (Valve/Strainer): Ball Valve**
**Filter Type (if fitted):**

**Pipe Diameter: 0.0136 m**
**Pipe Area: 0.000145267 m$^2$**

| Time for 18 Litres (s) | Flow Rate ($Q$) (m$^3$.s$^{-1}$) | Piezometer/Gauge Readings | | | Flow Velocity (m.s$^{-1}$) | $k$ Factor | Re |
|---|---|---|---|---|---|---|---|
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $\Delta h$ (m) | | | |
| 62 | 0.000290 | 702 | 450 | 0.252 | 1.999 | 1.2379 | $2.89 \times 10^4$ |
| 68 | 0.000265 | 672 | 459 | 0.213 | 1.822 | 1.2586 | $2.64 \times 10^4$ |
| 85 | 0.000212 | 610 | 475 | 0.135 | 1.458 | 1.2464 | $2.11 \times 10^4$ |
| 107 | 0.000168 | 571 | 481 | 0.090 | 1.158 | 1.3167 | $1.68 \times 10^4$ |
| 130 | 0.000138 | 549 | 487 | 0.062 | 0.953 | 1.3390 | $1.38 \times 10^4$ |

*Table 25 Results for Fully Open Ball Valve*

**Item (Valve/Strainer): Globe Valve**
**Filter Type (if fitted):**

**Pipe Diameter: 0.0136 m**
**Pipe Area: 0.000145267 m$^2$**

| Time for 18 Litres (s) | Flow Rate ($Q$) (m$^3$.s$^{-1}$) | Piezometer/Gauge Readings | | | Flow Velocity (m.s$^{-1}$) | $k$ Factor | Re |
|---|---|---|---|---|---|---|---|
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $\Delta h$ (m) | | | |
| 70 | 0.000257 | 881 | 335 | 0.546 | 1.770 | 3.4188 | $2.56 \times 10^4$ |
| 75 | 0.000240 | 840 | 342 | 0.498 | 1.652 | 3.5797 | $2.39 \times 10^4$ |
| 83 | 0.000217 | 782 | 376 | 0.406 | 1.493 | 3.5741 | $2.16 \times 10^4$ |
| 107 | 0.000168 | 680 | 432 | 0.248 | 1.158 | 3.6283 | $1.68 \times 10^4$ |
| 174 | 0.000103 | 581 | 485 | 0.096 | 0.712 | 3.7141 | $1.03 \times 10^4$ |

*Table 26 Results for Fully Open Globe Valve*

## Strainer

| Item (Valve/Strainer): Strainer<br>Filter Type (if fitted): 0.5 mm | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pipe Diameter: 0.017 m<br>Pipe Area: 0.00022698 m$^2$ | | | | | | | |
| Time for 18 Litres (s) | Flow Rate ($Q$) (m$^3$.s$^{-1}$) | Piezometer/Gauge Readings | | | Flow Velocity (m.s$^{-1}$) | $k$ Factor | Re |
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $\Delta h$ (m) | | | |
| 73 | 0.000247 | (Gauge) | (Gauge) | 2.038736 | 1.0863304 | 33.90 | $1.84 \times 10^4$ |
| 86 | 0.000209 | (Gauge) | (Gauge) | 1.529052 | 0.9221176 | 35.28 | $1.56 \times 10^4$ |
| 106 | 0.000170 | (Gauge) | (Gauge) | 1.019368 | 0.7481332 | 35.73 | $1.27 \times 10^4$ |
| 108 | 0.000167 | (Gauge) | (Gauge) | 1.005 | 0.7342789 | 36.57 | $1.24 \times 10^4$ |
| 161 | 0.000112 | (Gauge) | (Gauge) | 0.516 | 0.4925597 | 41.73 | $8.34 \times 10^3$ |
| 271 | 0.000066 | (Gauge) | (Gauge) | 0.25 | 0.2926277 | 57.28 | $4.95 \times 10^3$ |

*Table 27 Results for Strainer with 0.5 mm Filter*

| Item (Valve/Strainer): Strainer<br>Filter Type (if fitted): 1.4 mm | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pipe Diameter: 0.017 m<br>Pipe Area: 0.00022698 m$^2$ | | | | | | | |
| Time for 18 Litres (s) | Flow Rate ($Q$) (m$^3$.s$^{-1}$) | Piezometer/Gauge Readings | | | Flow Velocity (m.s$^{-1}$) | $k$ Factor | Re |
| | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $\Delta h$ (m) | | | |
| 83 | 0.000217 | (Gauge) | (Gauge) | 1.529052 | 0.9554472 | 32.863 | $1.62 \times 10^4$ |
| 100 | 0.000180 | (Gauge) | (Gauge) | 1.019368 | 0.7930212 | 31.802 | $1.34 \times 10^4$ |
| 114 | 0.000158 | (Gauge) | (Gauge) | 0.7 | 0.6956326 | 28.382 | $1.18 \times 10^4$ |
| 137 | 0.000131 | (Gauge) | (Gauge) | 0.45 | 0.5788476 | 26.350 | $9.80 \times 10^3$ |
| 182 | 0.000099 | (Gauge) | (Gauge) | 0.295 | 0.4357259 | 30.486 | $7.38 \times 10^3$ |
| 241 | 0.000075 | (Gauge) | (Gauge) | 0.161 | 0.3290544 | 29.174 | $5.57 \times 10^3$ |

*Table 28 Results for Strainer with 1.4 mm Filter*

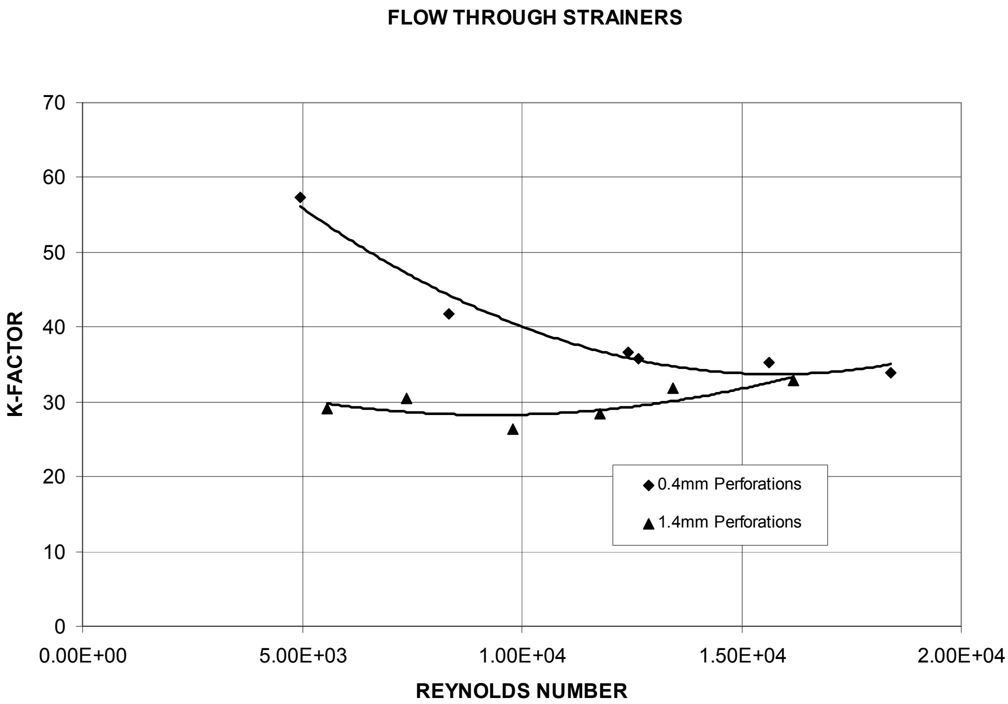


*Figure 23 Graph of k factor Against Reynolds Number for the Strainer*

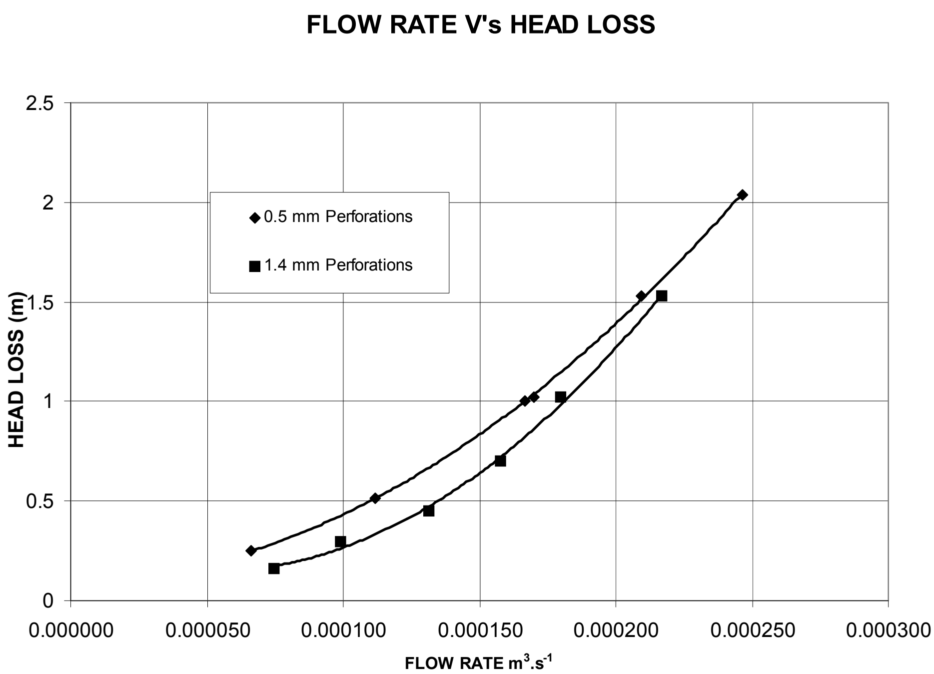


*Figure 24 Graph of Head Loss against Flow Rate for the Strainer*

## Valves (variable opening)

| Valve Type: Gate | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Valve Position | Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | % Flow Rate | Piezometer/Gauge Readings | | | Flow Velocity $m.s^{-1}$ | $k$ Factor | Re |
| | | | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $h$ (m) | | | |
| 100% (Fully Open) | 72 | 0.000250 | 100 | 625 | 509 | 0.116 | 1.721 | 0.77 | $2.49 \times 10^4$ |
| 80% | 73 | 0.000247 | 99 | 628 | 507 | 0.121 | 1.697 | 0.82 | $2.46 \times 10^4$ |
| 60% | 74 | 0.000243 | 97 | 655 | 482 | 0.173 | 1.674 | 1.21 | $2.42 \times 10^4$ |
| 40% | 75 | 0.000240 | 96 | 750 | 393 | 0.357 | 1.652 | 2.57 | $2.39 \times 10^4$ |
| 20% | 107 | 0.000168 | 67 | (gauge) | (gauge) | 2.220 | 1.158 | 32.48 | $1.68 \times 10^4$ |
| 15% | 189 | 0.000095 | 38 | (gauge) | (gauge) | 4.020 | 0.656 | 183.50 | $9.49 \times 10^3$ |
| 10% | 468 | 0.000038 | 15 | (gauge) | (gauge) | 4.620 | 0.265 | 1293.07 | $3.83 \times 10^3$ |

*Table 29 Results for Gate Valve with Variable Opening*

| Valve Type: Ball | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Valve Position | Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | % Flow Rate | Piezometer/Gauge Readings | | | Flow Velocity $m.s^{-1}$ | $k$ Factor | Re |
| | | | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $h$ (m) | | | |
| 100% (Fully Open) | 73 | 0.000247 | 100 | 407 | 212 | 0.195 | 1.697 | 1.33 | $2.46 \times 10^4$ |
| 80% | 75 | 0.000240 | 97 | 418 | 210 | 0.208 | 1.652 | 1.50 | $2.39 \times 10^4$ |
| 60% | 77 | 0.000234 | 94 | 565 | 80 | 0.485 | 1.609 | 3.67 | $2.33 \times 10^4$ |
| 40% | 88 | 0.000205 | 83 | (gauge) | (gauge) | 2.200 | 1.408 | 21.77 | $2.04 \times 10^4$ |
| 20% | 486 | 0.000037 | 15 | (gauge) | (gauge) | 5.600 | 0.255 | 1690.25 | $3.69 \times 10^3$ |
| 15% | 491 | 0.000037 | 15 | (gauge) | (gauge) | 5.900 | 0.252 | 1817.63 | $3.65 \times 10^3$ |

*Table 30 Results for Ball Valve with Variable Opening*

| Valve Type: Globe | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Valve Position | Time for 18 Litres (s) | Flow Rate ($Q$) ($m^3.s^{-1}$) | % Flow Rate | Piezometer/Gauge Readings | | | Flow Velocity $m.s^{-1}$ | $k$ Factor | Re |
| | | | | Upstream Tapping (mm) | Downstream Tapping (mm) | Difference $h$ (m) | | | |
| 100% (Fully Open) | 70 | 0.000257 | 100 | 1038 | 408 | 0.630 | 1.770 | 3.94 | $2.56 \times 10^4$ |
| 80% | 71 | 0.000254 | 99 | 1042 | 399 | 0.643 | 1.745 | 4.14 | $2.52 \times 10^4$ |
| 60% | 71 | 0.000254 | 99 | 1060 | 387 | 0.673 | 1.745 | 4.34 | $2.52 \times 10^4$ |
| 30% | 72 | 0.000250 | 97 | 1121 | 334 | 0.787 | 1.721 | 5.21 | $2.49 \times 10^4$ |
| 20% | 74 | 0.000243 | 94 | 1210 | 240 | 0.970 | 1.674 | 6.79 | $2.42 \times 10^4$ |
| 10% | 85 | 0.000212 | 82 | (Gauge) | (Gauge) | 1.970 | 1.458 | 18.19 | $2.11 \times 10^4$ |
| 7.5% | 103 | 0.000175 | 68 | (Gauge) | (Gauge) | 3.420 | 1.203 | 46.36 | $1.74 \times 10^4$ |
| 5% | 159 | 0.000113 | 44 | (Gauge) | (Gauge) | 3.970 | 0.779 | 128.25 | $1.13 \times 10^4$ |

*Table 31  Results for Globe Valve with Variable Opening*

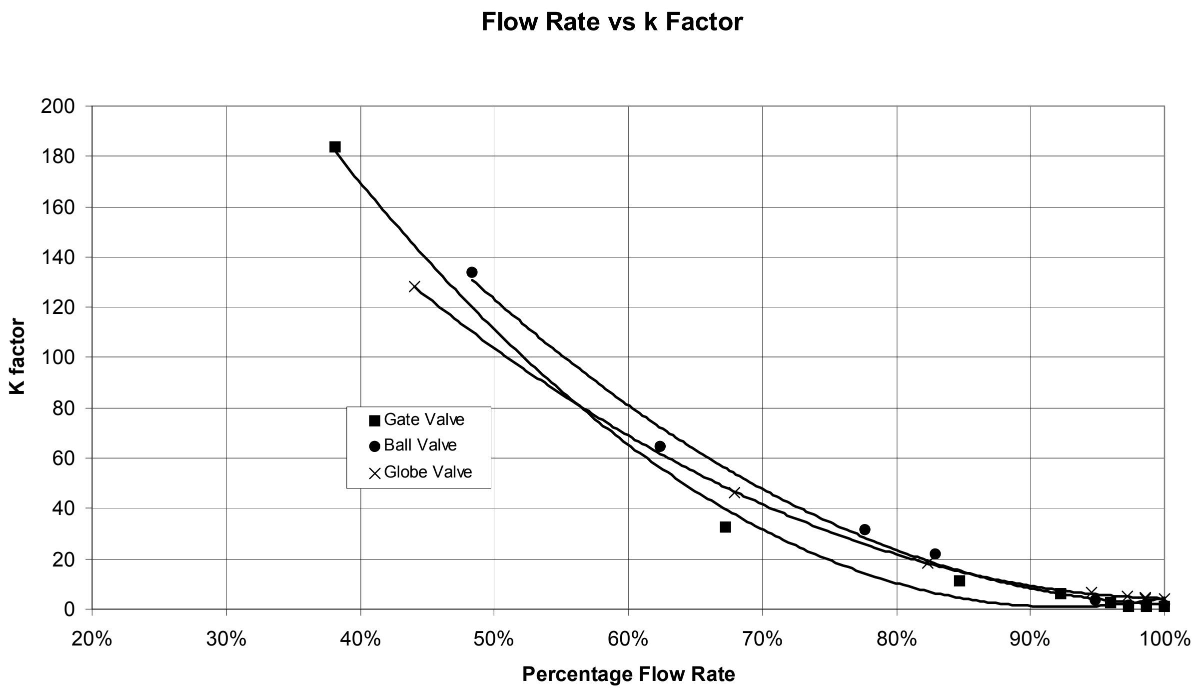


*Figure 25 Graph of % Flow Rate against k Factor*

## 5.5 *Flow Measurement Experiments*

### Pitot Traverse

| Pitot Position (mm) | Radius from pipe centre (mm) | Radius² $r^2$ (m²) | Pressure Difference $\Delta h$ (mm water) | Flow Velocity $u$ ($\sqrt{2g\Delta h}$) m.s⁻¹ | Simpsons Rule ($\Delta r$ x $\Delta u/2$) |
|---|---|---|---|---|---|
| 10.925 | 0 | 0 | 44 | 0.929129 | |
| 8.925 | 2 | 40 x $10^{-6}$ | 44 | 0.929129 | 3.71651 x $10^{-6}$ |
| 6.925 | 4 | 1.60 x $10^{-5}$ | 44 | 0.929129 | 1.11495 x $10^{-5}$ |
| 4.925 | 6 | 3.60 x $10^{-5}$ | 44 | 0.929129 | 1.85826 x $10^{-5}$ |
| 2.925 | 8 | 6.40 x $10^{-5}$ | 44 | 0.929129 | 2.60156 x $10^{-5}$ |
| 2.425 | 8.5 | 7.23 x $10^{-5}$ | 43 | 0.91851 | 7.62151 x $10^{-6}$ |
| 1.925 | 9 | 8.10 x $10^{-5}$ | 41 | 0.896895 | 7.94239 x $10^{-6}$ |
| 1.425 | 9.5 | 9.03 x $10^{-5}$ | 39 | 0.874746 | 8.19384 x $10^{-6}$ |
| 0.925 | 10 | 1.0 x $10^{-4}$ | 36 | 0.840428 | 8.36147 x $10^{-6}$ |
| | Theoretical Maximum Radius = 10.925 | Theoretical Maximum Radius² = 1.19 x $10^{-4}$ | | Theoretical Velocity at Maximum Radius = 0 | Flow rate = 3.133 x $10^{-4}$ $m^3.s^{-1}$ (sum of this column) |

*Table 32 Results for Pitot Traverse*

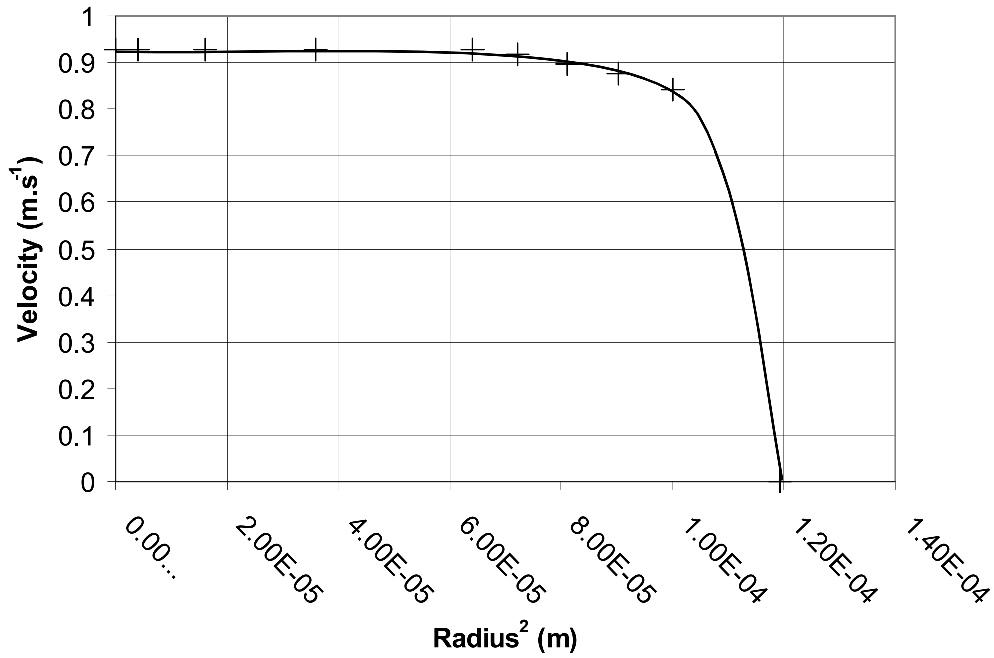


*Figure 26 Results for Pitot Traverse*

# SECTION 6.0 MAINTENANCE, SPARE PARTS AND CUSTOMER CARE

## *6.1 General Maintenance*

If the apparatus is not to be used for several weeks, drain out all the water.

To clean the apparatus, wipe clean with a damp cloth - do not use abrasive cleaners.

Make sure the Pitot Micrometer is clean and dry after use. Regularly lubricate it with some light oil to prevent corrosion.

## *6.2 Spare Parts*

Check the Packing Contents List to see what spare parts we send with the apparatus.

If you need technical help or spares, please contact your local TecQuipment Agent, or contact TecQuipment direct.

When you ask for spares, please tell us:

- Your Name
- The full name and address of your college, company or institution
- Your email address
- The TecQuipment product name and product reference
- The TecQuipment part number (if you know it)
- The serial number
- The year it was bought (if you know it)

Please give us as much detail as possible about the parts you need and check the details carefully before you contact us.

If the product is out of warranty, TecQuipment will let you know the price of the spare parts.

## *6.3 Customer Care*

We hope you like our products and manuals. If you have any questions, please contact our Customer Care department:

Telephone: +44 115 954 0155

Fax: +44 115 973 1520

email: **customercare@tecquipment.com**

For information about all TecQuipment Products and Services, visit:

www.tecquipment.com

# Air Valves

## TecQuipment's

## Fluid Mechanics Products

# Instruction Sheets

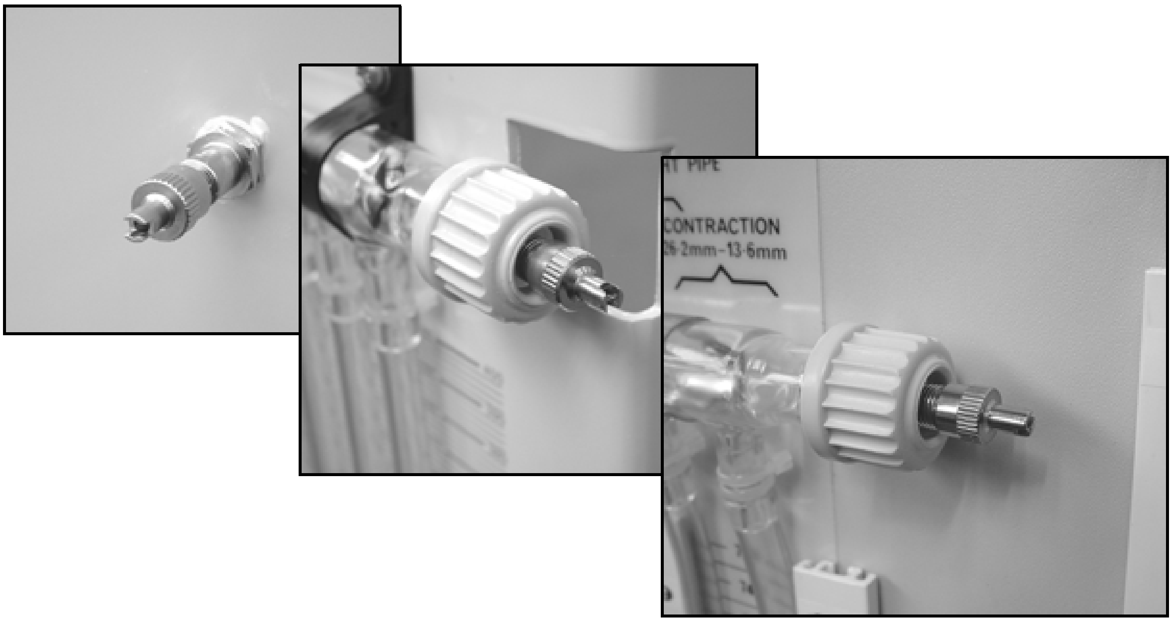


*Figure 27 Typical Air Valves on Some of TecQuipments Products*

Many of the products in TecQuipment's Fluid Mechanics range use air valves at the tops of manometers or piezometers. The valves keep the air in the manometer tubes to allow you to offset the pressure range of the manometer or piezometer.

The valves are similar to valves used in vehicle tyres and include a special cap. The hand pump supplied with the equipment is similar to those used for bicycle tyres, except that TecQuipment remove the cross-shape part of the flexible pipe.

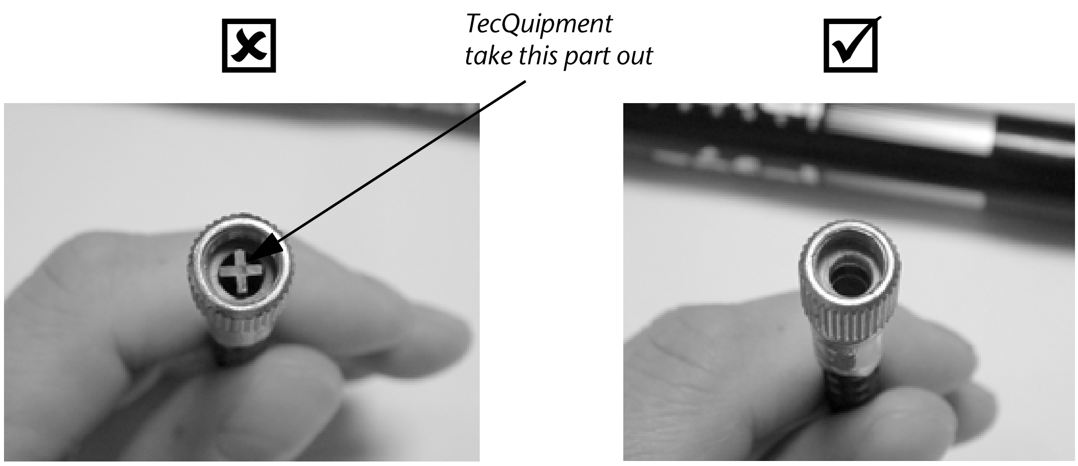


*Figure 28 TecQuipment Remove the Cross-shape Part of the Flexible Pipe*

Normally, when you connect the flexible pipe to an air valve, the cross-shape piece in the flexible pipe pushes open the valve as you pump air with the hand pump. With TecQuipment fluid mechanics products, this could allow water back out through the valve. For this reason TecQuipment remove the cross-shape piece. Without the cross-shape piece, only pressurised air can go through the valve in one direction, and no water can come back out.

*Figure 29  The Hand Pump and Flexible Pipe*

When you first use the hand pump with the air valve, you may find it hard to push air through the valve. This is because the valve is new and you do not have the cross-shape piece to help push it open. The valve will open more easily after you have pumped air through it a few times.

You may need some practice to use the air valve. To do it correctly:

1. Unscrew the cap from the valve.

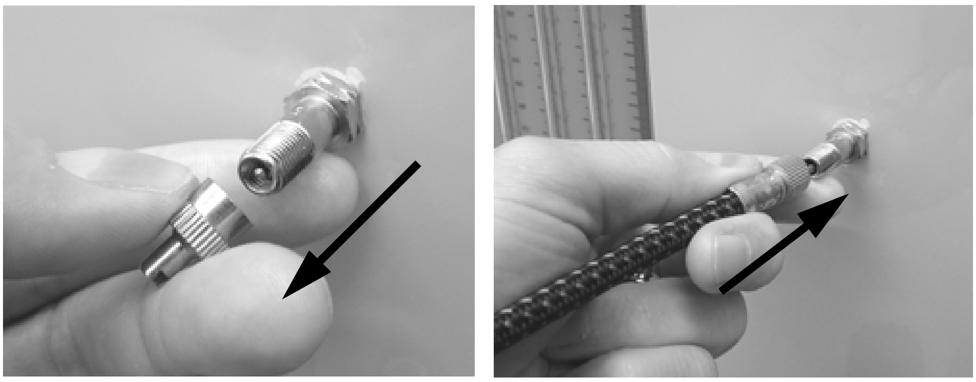

*Figure 30  Unscrew the Cap and Fit the Pipe*

2. Connect the flexible pipe to the valve.
3. Connect the hand pump to the flexible pipe.
4. Using complete strokes, ***slowly and firmly*** pump the hand pump to force air into the manometer or piezometer.
5. Unscrew the hand pump and flexible pipe and refit the valve cover.
6. To let air back out through the air valve, use the end of the special cap to press on the inner part of the valve (see Figure 31).

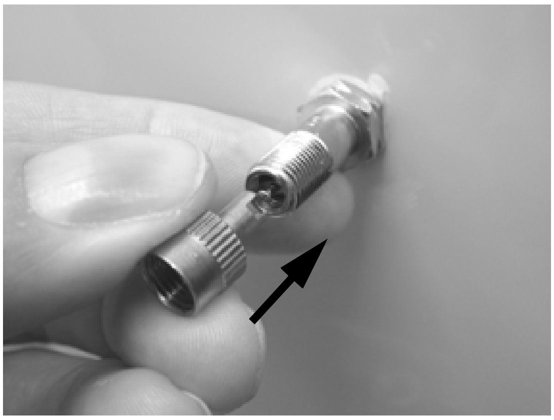

*Figure 31  To Let Air Out - Use the End of the Special Cap to Press the Inner Part of the Valve*

**WARNING**

***Take care when you let air back out from the air valve. Water may come out!***

***Clean up any water spills immediately.***

If using the hand pump is too difficult, the valve may be stuck. If you need to check the valve is working, use the special cap to unscrew the valve, then gently press the end of the valve. It should move easily and return back to its original position (see Figure 32).

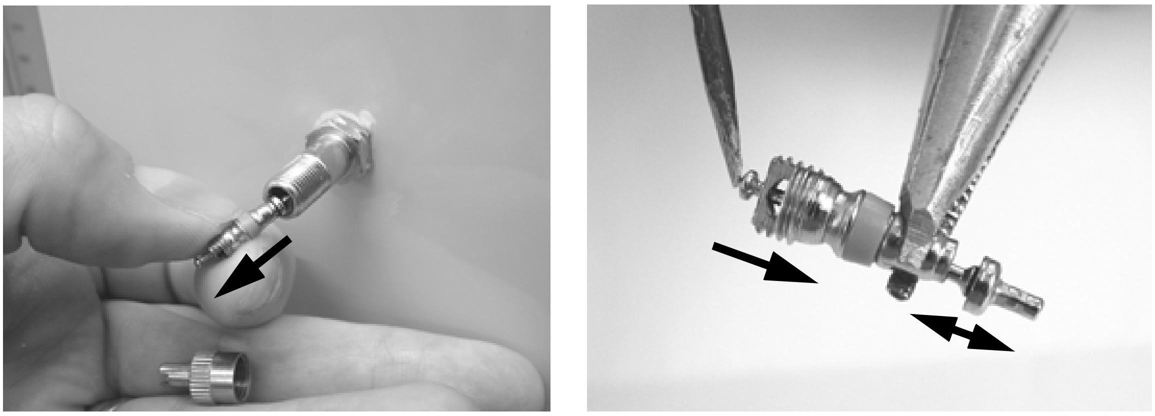

*Figure 32  Unscrew the Valve and Check it*

If the valve does not move easily, then contact TecQuipment Customer Services for help.

Telephone: +44 115 9722611

Fax: +44 115 973 1520

Email: **customer.care@tecquipment.com**

TecQuipment 0809 DB