Fluid Friction Apparatus

Instruction Manual

C6-MKII-10

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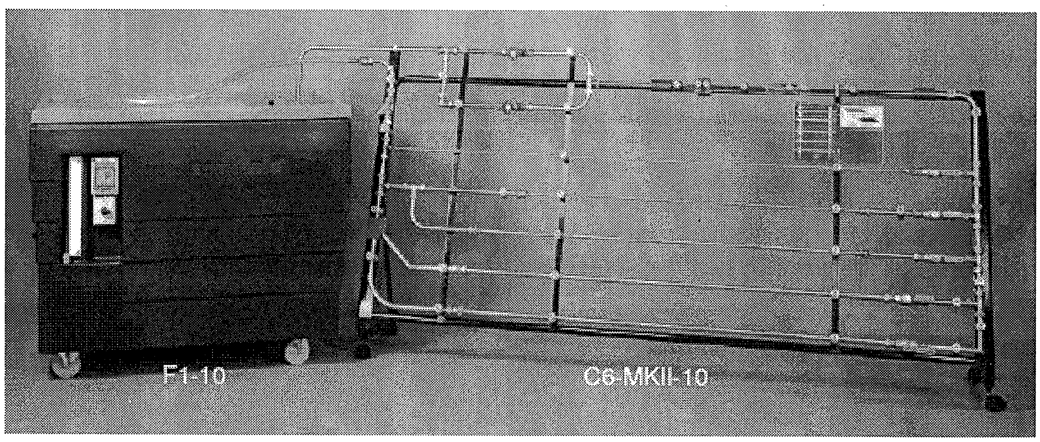
General Overview

The Armfield C6-MKII-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 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.

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.

The C6-MKII-10 is designed to be operated in conjunction with the Armfield F1-10 Hydraulics Bench. The unit can be used with a range of instrumentation packages including water and mercury manometers, hand-held digital pressure meters and a computer data logging pack.



C6-MKII Fluid Friction Apparatus

Equipment Diagrams

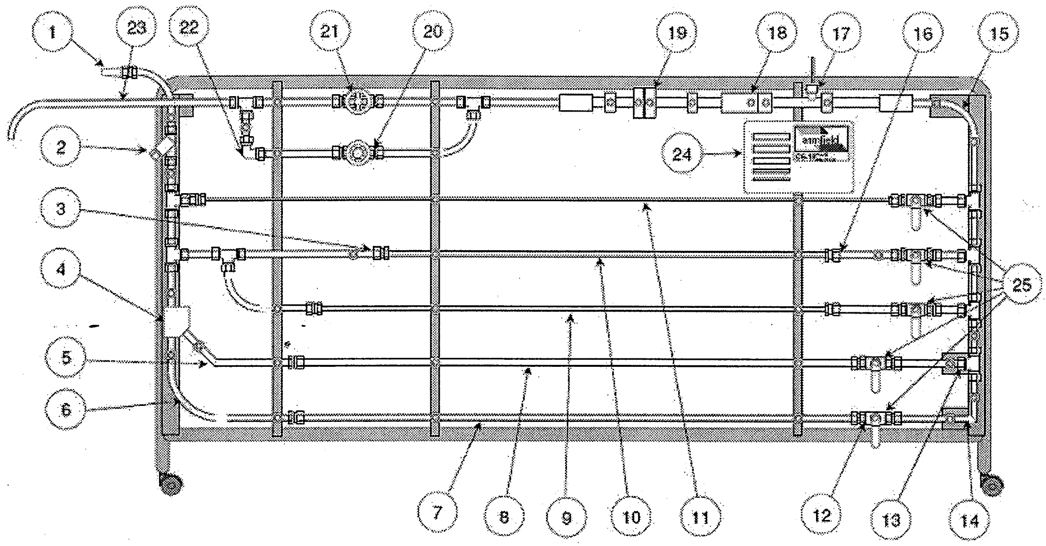


Figure 1: General Arrangement of C6-MKII-10 Fluid Friction Apparatus

Important Safety Information

Introduction

All practical work areas and laboratories should be covered by local safety regulations **which must be followed at all times.**

It is the responsibility of the owner to ensure that all users are made aware of relevant local regulations, and that the apparatus is operated in accordance with those regulations. If requested then Armfield can supply a typical set of standard laboratory safety rules, but these are guidelines only and should be modified as required. Supervision of users should be provided whenever appropriate.

Your **C6-MKII-10 Fluid Friction Apparatus** has been designed to be safe in use when installed, operated and maintained in accordance with the instructions in this manual. As with any piece of sophisticated equipment, dangers exist if the equipment is misused, mishandled or badly maintained.

Water Borne Hazards

The equipment described in this instruction manual involves the use of water, which under certain conditions can create a health hazard due to infection by harmful micro-organisms.

For example, the microscopic bacterium called Legionella pneumophila will feed on any scale, rust, algae or sludge in water and will breed rapidly if the temperature of water is between 20 and 45°C. Any water containing this bacterium which is sprayed or splashed creating air-borne droplets can produce a form of pneumonia called Legionnaires Disease which is potentially fatal.

Legionella is not the only harmful micro-organism which can infect water, but it serves as a useful example of the need for cleanliness.

Under the COSHH regulations, the following precautions must be observed:

- Any water contained within the product must not be allowed to stagnate, ie. the water must be changed regularly.
- Any rust, sludge, scale or algae on which micro-organisms can feed must be removed regularly, i.e. the equipment must be cleaned regularly.
- Where practicable the water should be maintained at a temperature below 20°C. If this is not practicable then the water should be disinfected if it is safe and appropriate to do so. Note that other hazards may exist in the handling of biocides used to disinfect the water.
- A scheme should be prepared for preventing or controlling the risk incorporating all of the actions listed above.

Further details on preventing infection are contained in the publication “The Control of Legionellosis including Legionnaires Disease” - Health and Safety Series booklet HS (G) 70.

Description

Where necessary, refer to the drawings in the Equipment Diagrams section.

Overview

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 facilities for testing the following:

- 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 minimise 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.

C6-50 Data Logging Accessory

The C6-50 Data Logging Accessory consists of a turbine type flow meter, two pressure sensors with quick release connectors and a signal conditioning and interface console.

The unit is powered by a separate power supply unit and is connected to the computer via a USB socket at the rear. Two LEDs on the front panel illuminate when the unit is powered and active.

The C6-50 is supplied with software on CD-ROM. The following are minimum computer requirements:

- Pentium Processor
- 32MB RAM
- CD-ROM Drive
- 15MB Hard Disk Space
- SVGA Display (800 x 600)
- USB Port
- Windows 98, ME, 2000 or XP

The software provides a mimic diagram with sensor readings and calculated variables superimposed in real time. Results can be stored in a spreadsheet and displayed in graphical format. The software also includes full help facilities.

Refer to the separate instruction manual supplied with C6-50 for details about connecting and operating the Data Logging accessory.

Installation

Advisory

Before operating the equipment, it must be unpacked, assembled and installed as described in the steps that follow. Safe use of the equipment depends on following the correct installation procedure.

Installation Process

1. Connect the F1-10 Hydraulics Bench to a suitable electrical supply. The supply MUST BE EARTHED. Test the RCD before continuing.

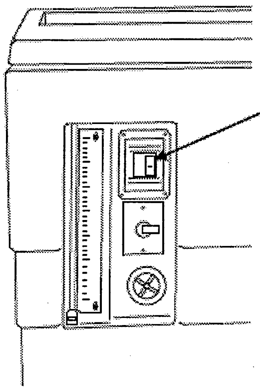
a) Fit an appropriate plug to the end of the power cable (if necessary). The socket you connect to must be earthed.

The electrical supply must be as follows:

Version	Voltage	Cycles	Fuse
F1-10-A	220	50	3A
F1-10-B	110	50	5A
F1-10-G	220	60	3A

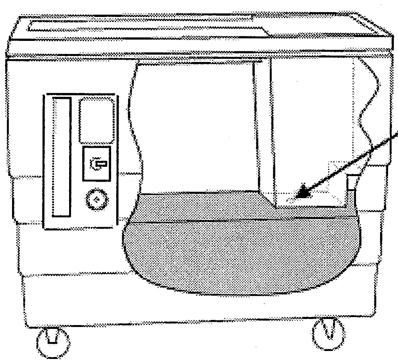
Consult the F1-10 Product Manual for further details.

If the equipment is used in an environment where it may become electrically live, Armfield recommend that the pipework is earthed using the strap provided.



b) Test the RCD. The device MUST trip when the button is pressed. If it does not, consult a competent electrician.

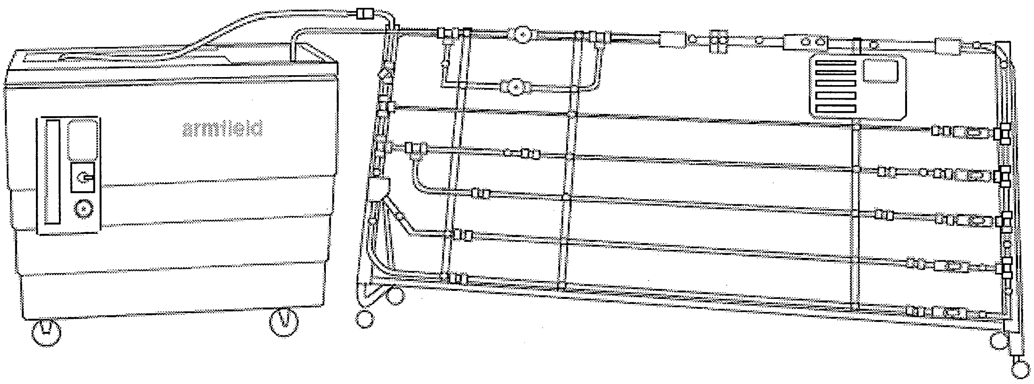
2. Fill the hydraulics bench sump tank with water.



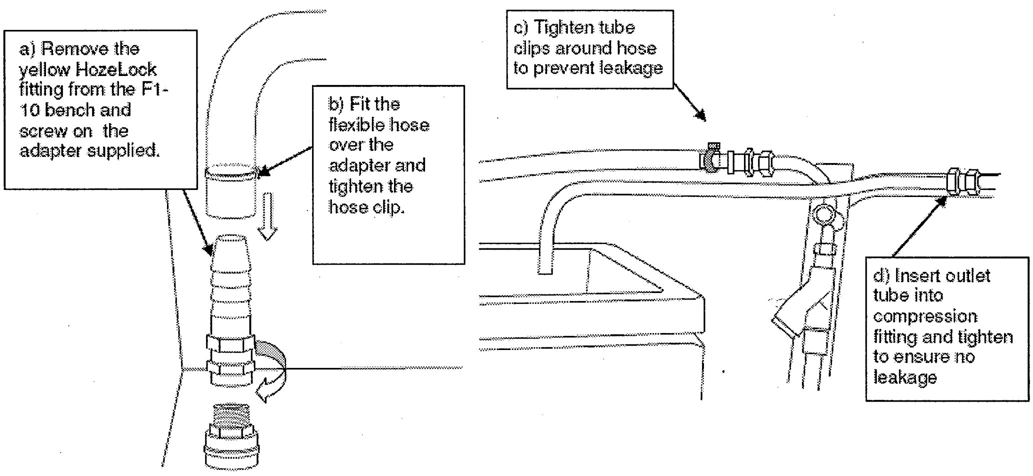
a) Fill the hydraulics bench via the dump valve in the bottom of the volumetric tank.

The level should be just beneath the dump valve.

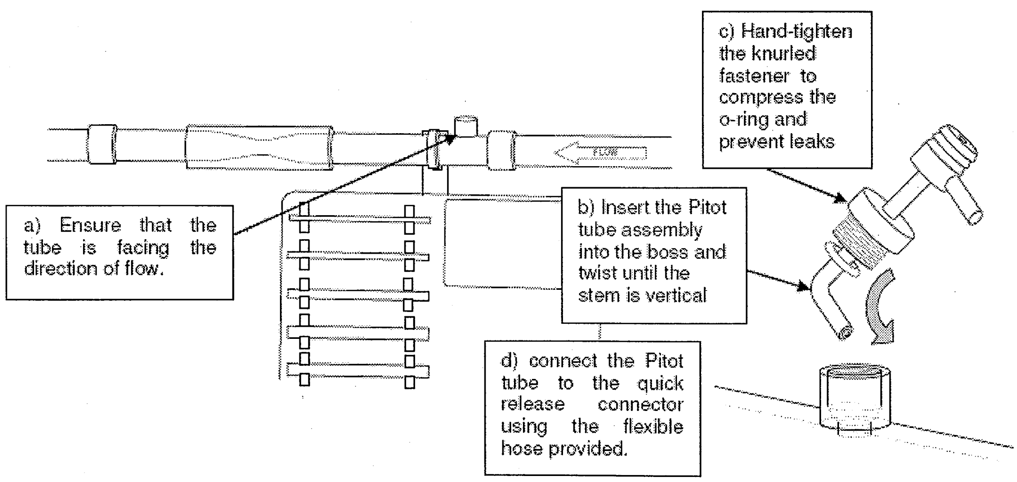
3. Position the pipe network (C6-10) next to the hydraulics bench (F1-10), with the outlet pipe from the pipe network over the volumetric tank. Ensure that the stilling baffle is in place in the volumetric tank.



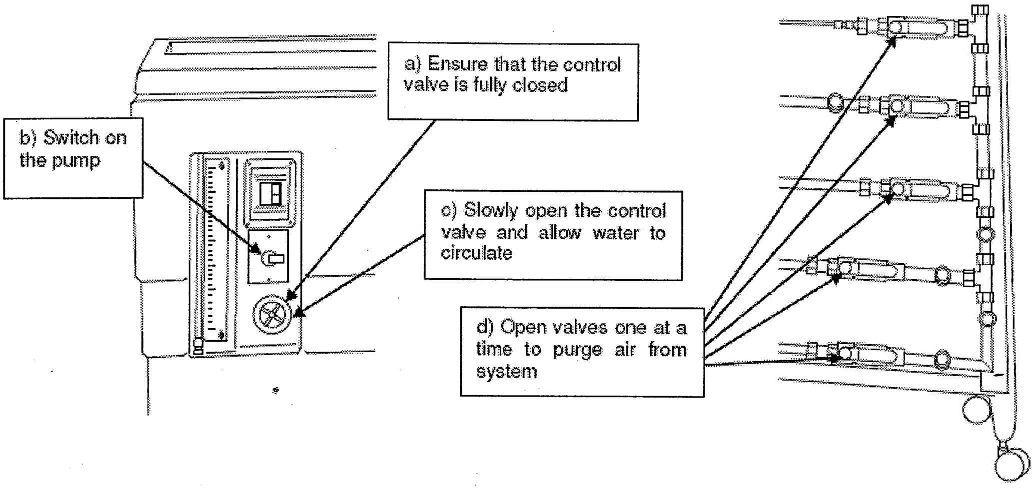
4. Connect the C6-MKII-10 the F1-10. Use the plastic hose clips provided to clamp the flexible hose to the inlet to the pipe network.



5. Fit the Pitot tube into the acrylic pipe section.



6. Switch on the pump and prime the system.



Operation

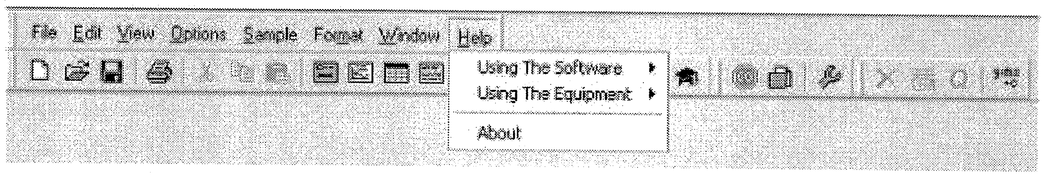
Where necessary, refer to the drawings in the Equipment Diagrams section.

The apparatus must be set up in accordance with the Installation section.

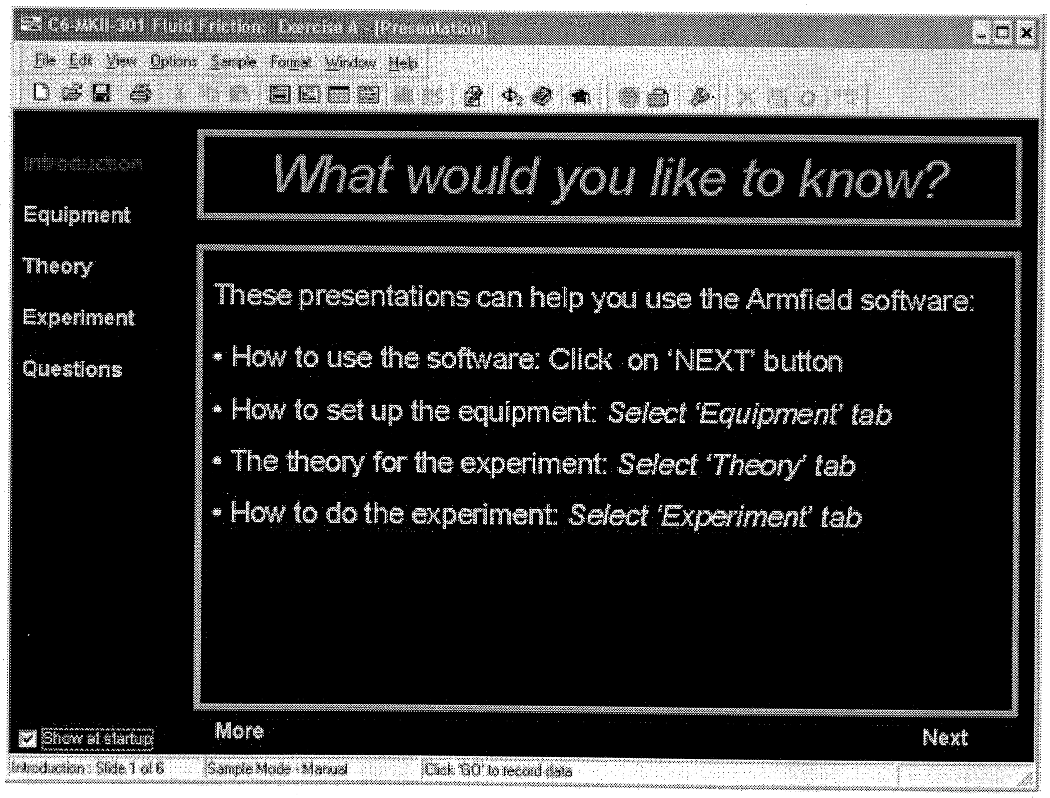
Operating the Software

Note: The diagrams in this section are included as typical examples and may not relate specifically to an individual product.

The Armfield Software is a powerful Educational and Data Logging tool with a wide range of features. Some of the major features are highlighted below, to assist users, but full details on the software and how to use it are provided in the presentations and Help text incorporated in the Software. Help on Using the Software or Using the Equipment is available by clicking the appropriate topic in the **Help** drop-down menu from the upper toolbar when operating the software as shown:



Load the software. If multiple experiments are available then a menu will be displayed listing the options. Wait for the presentation screen to open fully as shown:

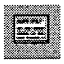


Presentation Screen - Basics and Navigation

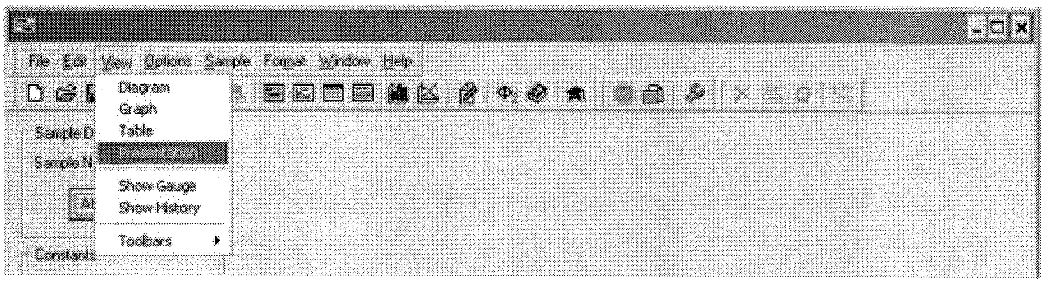
As stated above, the software starts with the Presentation Screen displayed. The user is met by a simple presentation which gives them an overview of the capabilities of the equipment and software and explains in simple terms how to navigate around the software and summarizes the major facilities complete with direct links to detailed context sensitive 'help' texts.

To view the presentations click **Next** or click the required topic in the left hand pane as appropriate. Click **More** while displaying any of the topics to display a Help index related to that topic.

To return to the Presentation screen at any time click the View Presentation icon



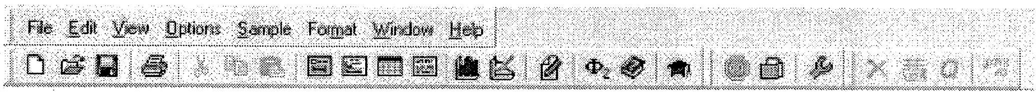
from the main tool bar or click **Presentation** from the dropdown menu as shown:



For more detailed information about the presentations refer to the **Help** available via the upper toolbar when operating the software.

Toolbar

A toolbar is displayed at the top of the screen at all times, so users can jump immediately to the facility they require, as shown:

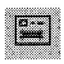


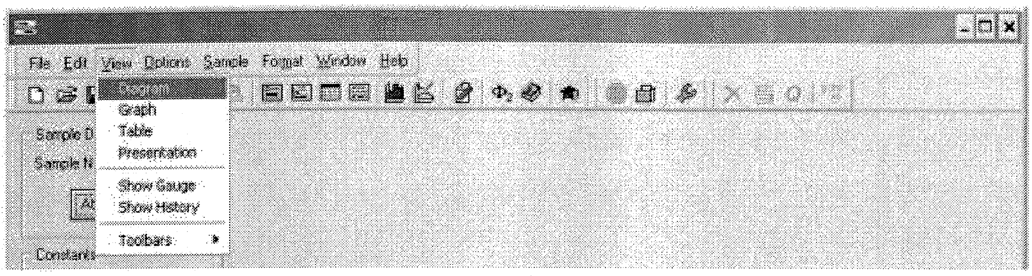
The upper menu expands as a dropdown menu when the cursor is placed over a name.

The lower row of icons (standard for all Armfield Software) allows a particular function to be selected. To aid recognition, pop-up text names appear when the cursor is placed over the icon.

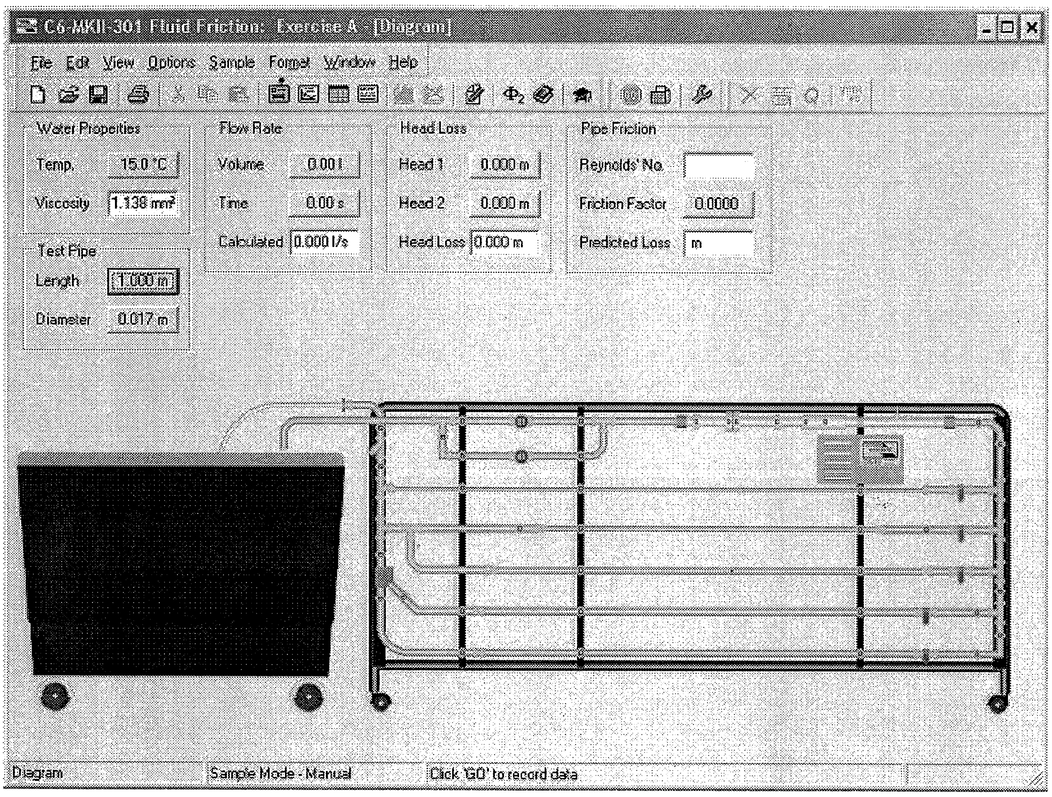
Mimic Diagram

The Mimic Diagram is the most commonly used screen and gives a pictorial representation of the equipment, with boxes to enter measurements from the equipment, display any calculated variables etc. directly in engineering units.

To view the Mimic Diagram click the View Diagram icon  from the main tool bar or click **Diagram** from the **View** drop-down menu as shown:



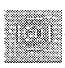
A Mimic diagram is displayed, similar to the diagram as shown:



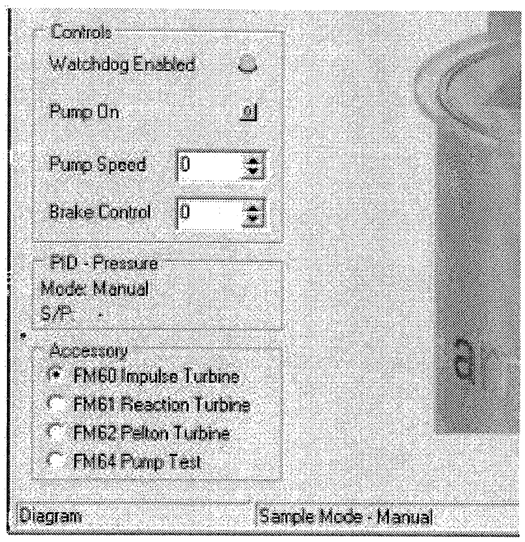
The details in the diagram will vary depending on the equipment chosen if multiple experiments are available.

Manual data input boxes with a coloured background allow measured variables, constants such as Orifice Cd and Atmospheric Pressure, as appropriate, to be changed by over-typing the default value. After typing the value press the Return key or click on a different box to enter the value.

In addition to measured variables such as Volume, Time, Temperature or Pressure, calculated data such as Discharge / Volume flowrate, Headloss etc are continuously displayed in data boxes with a white background. These are automatically updated and cannot be changed by the user.

After entering a complete set of data from measurements on the equipment click on the  icon to save the set of results before entering another set.

The mimic diagram associated with some products includes the facility to select different experiments or different accessories, usually on the left hand side of the screen, as shown:



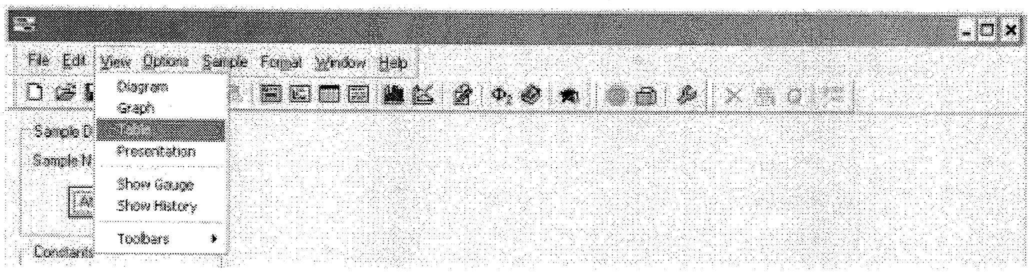
Clicking on the appropriate accessory or exercise will change the associated mimic diagram, table, graphs etc to suit the exercise being performed.

Data Logging Facilities in the Mimic Diagram

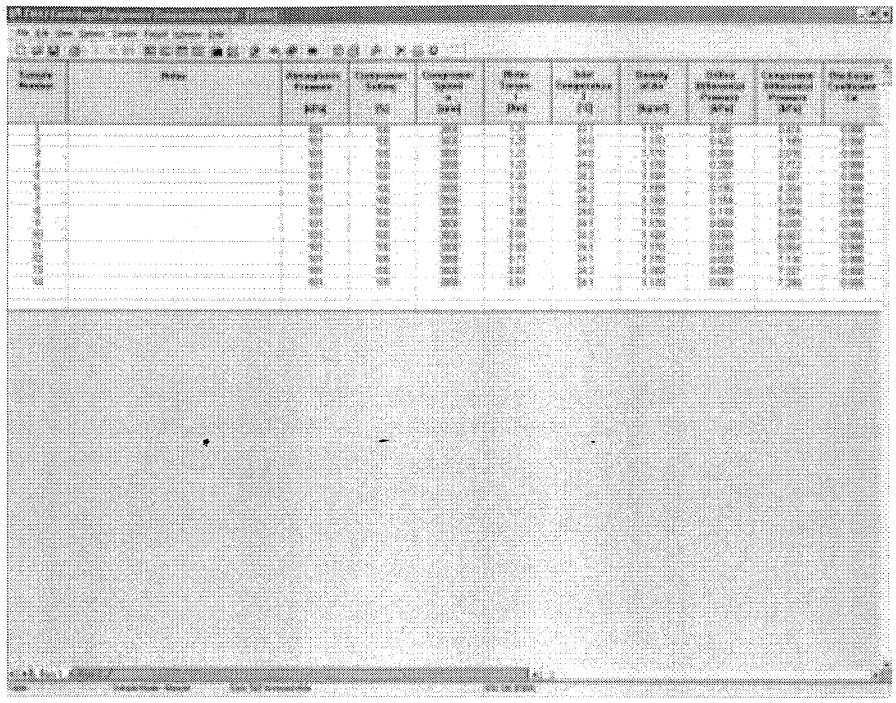
Armfield software designed for manual entry of measured variables does not include automatic data logging facilities and these options are greyed out where not appropriate. When manually entering data the icon simply saves the set of entered data into a spreadsheet as described above.

Tabular Display

To view the Table screen click the View Table icon from the main tool bar or click **Table** from the View dropdown menu as shown:



The data is displayed in a tabular format, similar to the screen as shown:



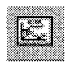
As the data is sampled, it is stored in spreadsheet format, updated each time the data is sampled. The table also contains columns for the calculated values.

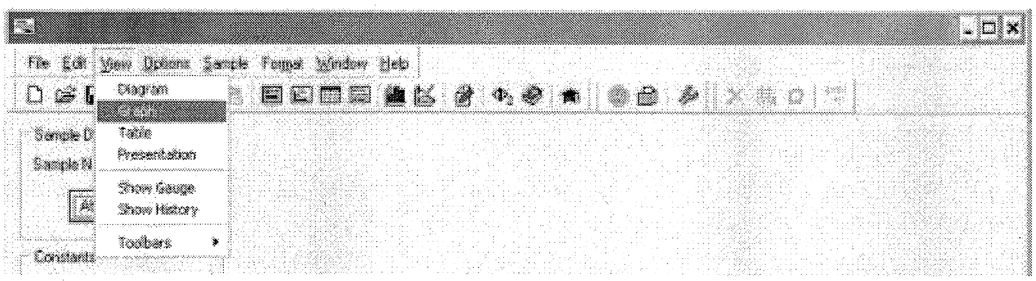
New sheets can be added to the spreadsheet for different data runs by clicking the  icon from the main toolbar. Sheets can be renamed by double clicking on the sheet name at the bottom left corner of the screen (initially Run 1, Run 2 etc) then entering the required name.

For more detailed information about Data Logging and changing the settings within the software refer to the **Help** available via the upper toolbar when operating the software.

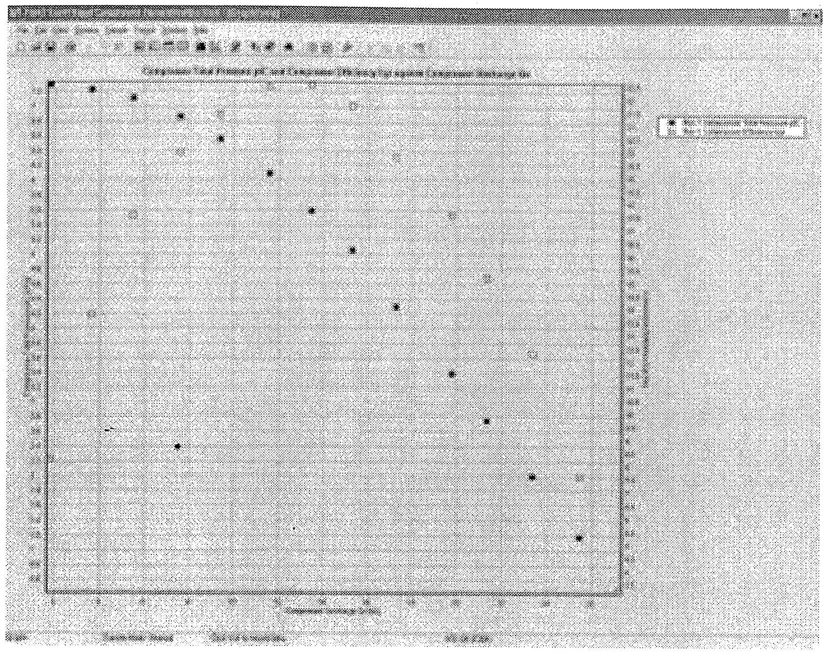
Graphical Display

When several samples have been recorded, they can be viewed in graphical format.

To view the data in Graphical format click the View graph icon  from the main tool bar or click **Graph** from the **View** drop-down menu as shown:



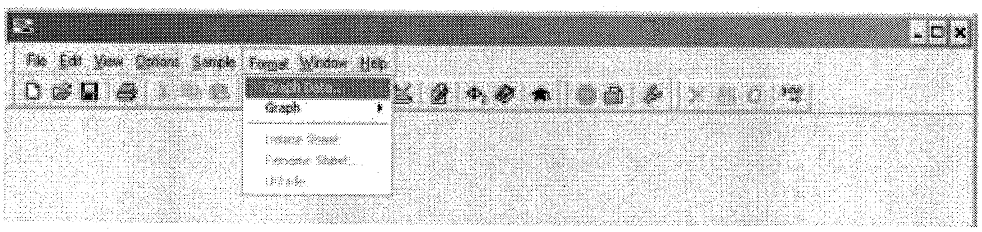
The results are displayed in a graphical format as shown:



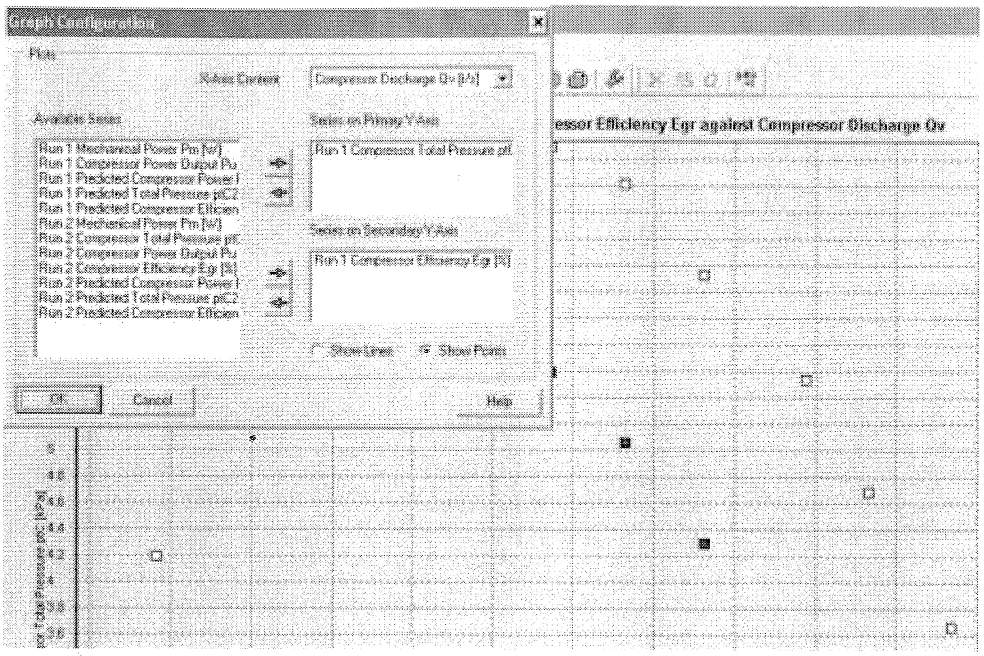
(The actual graph displayed will depend on the product selected and the exercise that is being conducted, the data that has been logged and the parameter(s) that has been selected).

Powerful and flexible graph plotting tools are available in the software, allowing the user full choice over what is displayed, including dual y axes, points or lines, displaying data from different runs, etc. Formatting and scaling is done automatically by default, but can be changed manually if required.

To change the data displayed on the Graph click **Graph Data** from the **Format** dropdown menu as shown:



The available parameters (Series of data) are displayed in the left hand pane as shown:



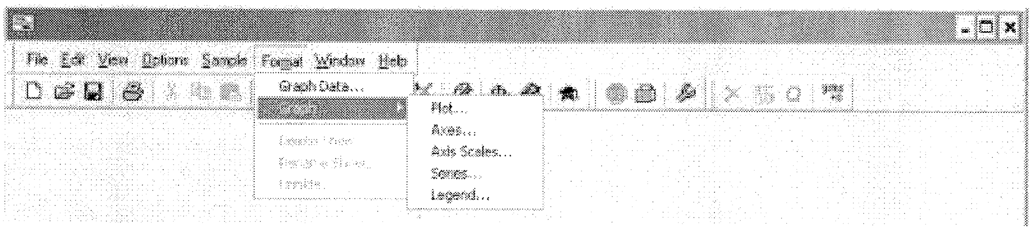
Two axes are available for plotting, allowing series with different scaling to be presented on the same x axis.

To select a series for plotting, click the appropriate series in the left pane so that it is highlighted then click the appropriate right-facing arrow to move the series into one of the windows in the right hand pane. Multiple series with the same scaling can be plotted simultaneously by moving them all into the same window in the right pane.

To remove a series from the graph, click the appropriate series in the right pane so that it is highlighted then click the appropriate left-facing arrow to move the series into the left pane.

The X-Axis Content is chosen by default to suit the exercise. The content can be changed if appropriate by opening the drop down menu at the top of the window.

The format of the graphs, scaling of the axes etc. can be changed if required by clicking **Graph** in the **Format** drop-down menu as shown:

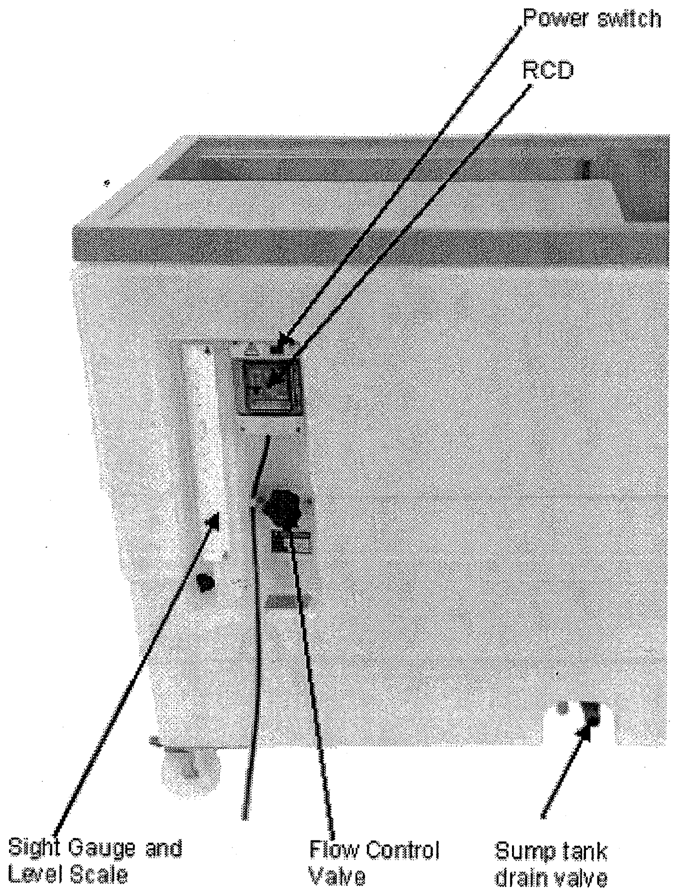


For more detailed information about changing these settings refer to the **Help** available via the upper toolbar when operating the software.

Operating the Equipment

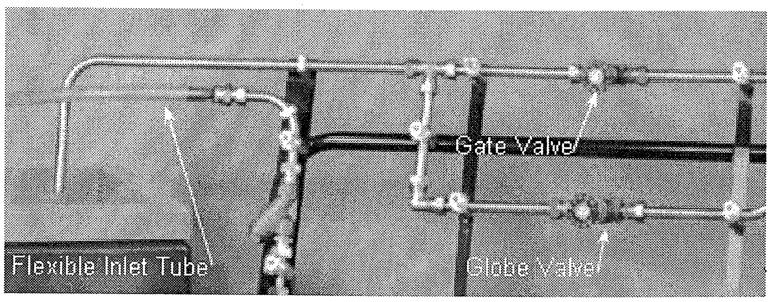
Controlling the Flow

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.



Hydraulics Bench Controls

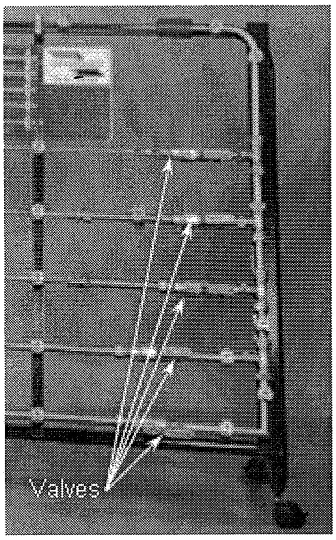
Water flows through the connector in the channel on the bench top, through the flexible connecting hose shown below and into the C6-MKII-10. It will then flow through whichever of the test pipes is selected, back through the acrylic pipe section and into the volumetric tank in the hydraulics bench.



Inlet and Outlet Pipe Arrangement

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.

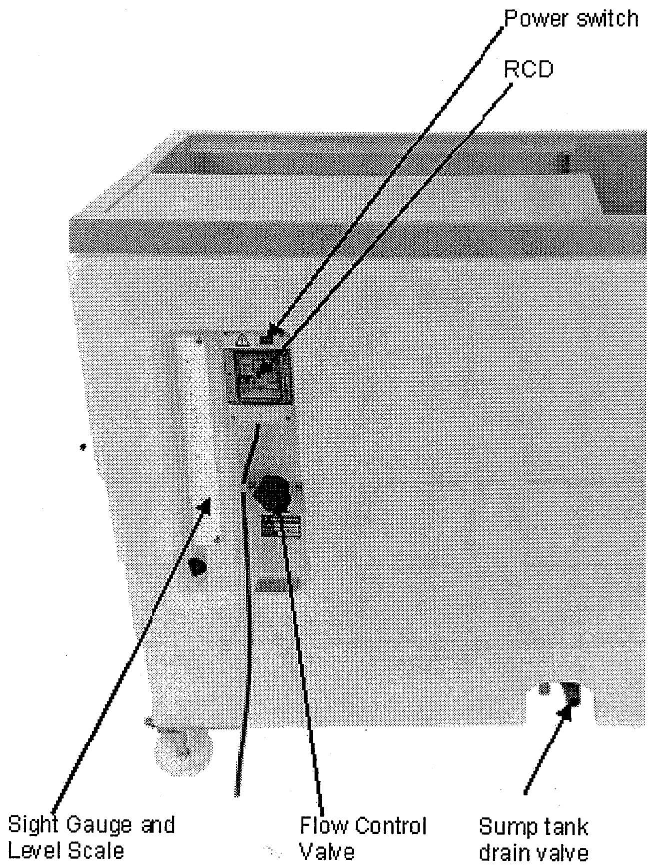


Isolating Valves

Volumetric Flow Measurement

The service module incorporates a moulded volumetric measuring tank which is stepped to accommodate low or high flow rates. A stilling baffle is incorporated to reduce turbulence.

A remote sight gauge (see below), consisting of a sight tube and scale, is connected to a tapping in the base of the tank and gives an instantaneous indication of water level. The scale is divided into two zones corresponding to the volume above and below the step in the tank.



Sight Gauge

A dump valve in the base of the volumetric tank is operated by a remote actuator. In operation, the volumetric tank is emptied by lifting the dump valve, allowing the entrained water to return to the sump. When test conditions have stabilised, the dump valve is lowered, retaining the water in the tank.

Timings are taken as the water level rises in the tank. Low flow rates are monitored on the lower portion of the scale corresponding to the small volume beneath the step. Larger flow rates are monitored on the upper scale corresponding to the main tank.

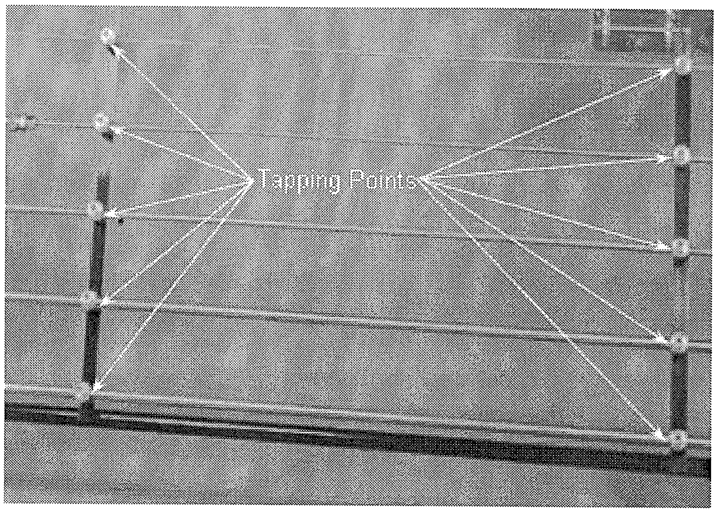
Before operation, the position of the scale relative to the tank should be adjusted as described in the F1-10 instruction manual.

When very small volumetric flow rates are to be measured, the measuring cylinder supplied with the F1-10 should be used rather than the volumetric tank. When using the measuring cylinder, diversion of the flow to and from the cylinder should be synchronised as closely as possible with the starting and stopping of a watch; do not attempt to use a definite time or a definite volume.

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

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 pressurised 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.

Operation with Hand Held Pressure Meter (e.g. Armfield H12-8)

Fit the quick release fittings supplied with the C6-MKII-10 to the ends of the tubes on the hand held pressure meter.

It is important to expel any air which may be trapped in the pipes of the pressure meter before taking readings. Close the globe valve and partly close the gate valve. Connect the meter tubes to a convenient pair of tappings (e.g. on the uppermost pipe) and switch on the pump. Carefully undo one of the nuts holding the tubing to the pressure meter until liquid is expelled from the joint. Bleed the tube to expel any air. Tighten the nut and repeat for the other tube.

When taking readings with the hand held pressure meter, it is important that the meter is zeroed bfore taking a set of results. With the pump still on, close the outlet valves and then close the control valve to leave the system at a high static pressure. When the reading on the meter has stabilised, press the zero button to reset the meter.

Operation with C6-50 Data Logging Accessory

The data logging accessory is supplied complete and ready for use. The console should be placed in a suitable location where it cannot be splashed by water. Although it contains no mains voltage components, the case is not watertight. The console must be powered using the adapter supplied.

Connect the two pressure sensors to the pair of tappings you wish to monitor. The flow meter measures the flow at the outlet from the C6-MKII-10.

When using the computer data logging accessory, it is important to calibrate the sensors in the software to achieve good accuracy. For the pressure sensors this will involve comparison with, for example, a suitable hand held meter, while the flow meter can be calibrated against timed volumetric measurements.

In order to obtain accurate results at very low flowrates and correspondingly small pressure differences, it may be necessary to use the volumetric flow measurement available on F1-10 and a pressurised water manometer or hand held pressure meter to achieve accurate readings. The software offers the choice of automatic data entry directly from the sensors or manual entry of readings taken from alternative instrumentation.

Refer to the separate instruction manual supplied with C6-50 for details about connecting and operating the Data Logging accessory.

For further assistance on calibrating the software to suit the sensors fitted, refer to the **Help** available via the upper toolbar when operating the software or refer to the separate C6-50 Instruction Manual.

Equipment Specifications

Overall Dimensions

Height - 1.10m

Length - 2.65m

Width - 0.50m

Test Pipe Diameters

1: 19.1mm x 17.2mm

2: 12.7mm x 10.9mm

3: 9.5mm x 7.7mm

4: 6.4mm x 4.5mm

5: 19.1mm x 15.2mm (artificially roughened)

Distance between tappings: 1.00m

Environmental Conditions

This equipment has been designed for operation in the following environmental conditions. Operation outside of these conditions may result reduced performance, damage to the equipment or hazard to the operator.

a. Indoor use;

b. Altitude up to 2000 m;

c. Temperature 5 °C to 40 °C;

d. Maximum relative humidity 80 % for temperatures up to 31 °C, decreasing linearly to 50 % relative humidity at 40 °C;

e. Mains supply voltage fluctuations up to ±10 % of the nominal voltage;

f. Transient over-voltages typically present on the MAINS supply;

NOTE: The normal level of transient over-voltages is impulse withstand (over-voltage) category II of IEC 60364-4-443;

g. Pollution degree 2.

Normally only nonconductive pollution occurs.

Temporary conductivity caused by condensation is to be expected.

Typical of an office or laboratory environment

Routine Maintenance

Responsibility

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular maintenance of the equipment is the responsibility of the end user and must be performed by qualified personnel who understand the operation of the equipment.

General

Water should be drained from all pipes in the network if the equipment will not be used in the near future. This may be facilitated by removing the sealing plug from the port below the ball valve (12) at the bottom of the network (take care not to lose the sealing washer). Place a suitable receptacle below the outlet to collect the water. Open all valves in the network including the inlet and outlet flow control valves. Disconnect the flexible inlet hose from the F1-10 Hydraulics Bench, to allow air to enter at the top, then close ball valve (12) partially (lever at approximately 45°) to allow water to drain into the receptacle. It may be necessary to open then close the ball valve several times to extract all of the water. After draining, open the ball valve (lever horizontal) then replace the sealing plug ensuring that the sealing washer is fitted.

Any pressure tapping which leaks unduly should be removed from the pipework and cleaned using compressed air. The most likely cause of leakage is grit between the seat and the sealing ball. The valves are not designed to seal 100% in normal operation and a small amount of water may drip from the tapping until the probe is inserted.

If any of the brass compression fittings leak, they can be tightened using an appropriate tool.

If the apparatus is to be left for prolonged periods, the Pitot tube assembly should be removed and stored in a safe place. See the Installation section for details on how to fit and remove the Pitot tube.

Laboratory Teaching Exercises

Index to Exercises

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.

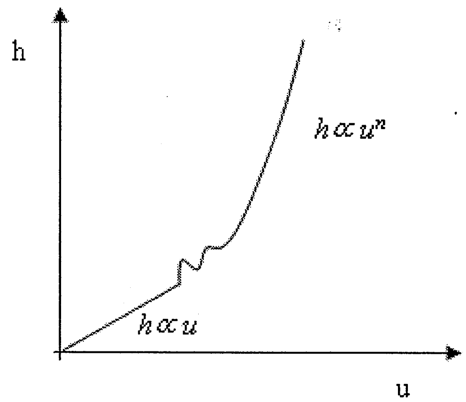
Theory

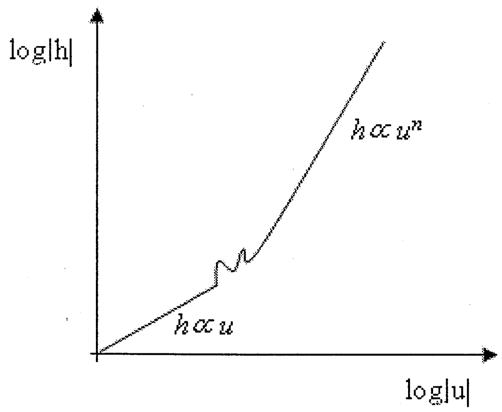
Professor Osborne Reynolds demonstrated that two types of flow may exist in a pipe.

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:

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

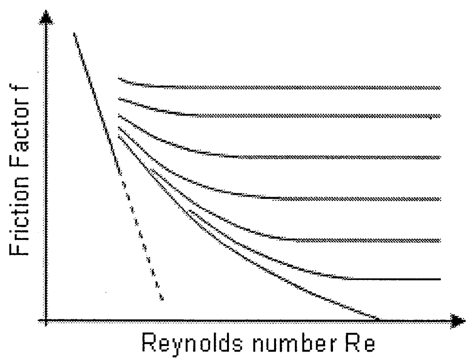
where L is the length of the pipe between tappings, d is the internal diameter of the pipe, u is the mean velocity of water through the pipe in m/s, g is the acceleration due to gravity in m/s^2 and f is pipe friction coefficient. Note that the American equivalent of the British term f is λ where $\lambda = 4f$.

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 (1.15×10^{-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.



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

Equipment Set Up

The equipment should be installed as described in the Installation section.

Additional equipment required: Stop watch, Internal Vernier calliper.

Arrange the valves on the C6-MKII-10 to allow flow through only the test pipe under observation.

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 A.

Procedure

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

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).

Measure flow rates using the volumetric tank (if using C6-304 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.

Obtain readings on all four smooth test pipes.

Measure the internal diameter of each test pipe sample using a Vernier calliper.

Processing Results

All readings should be tabulated as follows:

Volume V [litres]	Time T [Secs]	Flow rate Q [m³/s]	Pipe Diam. d [m]	Velocity u [m/s]	Reynolds No Re	λ	Calculated Head Loss hc [m H_2O]	Measured Head Loss h [m H_2O]
		$\frac{V \times 10^{-3}}{T}$		$\frac{4Q}{\pi d^2}$	$\frac{\rho u d}{\mu}$	From MOODY Diagram	$\frac{\lambda L u^2}{2gd}$	(h_C-h_D)

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 $h \propto u$.

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.

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.

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

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 μ is 1.15 x 10^{-3} Ns/m^2 at 15°C and the density ρ is 999 kg/m^3 at 15°C.

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:

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

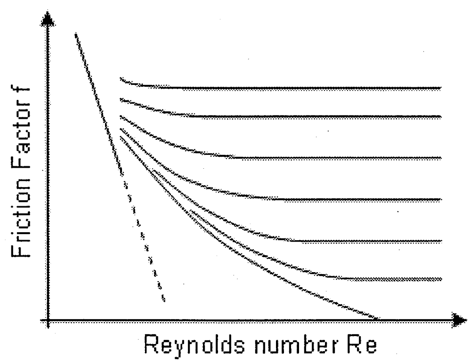
where L is the length of the pipe between tappings, d is the internal diameter of the pipe, u is the mean velocity of water through the pipe in m/s, g is the acceleration due to gravity in m/s^2 and f is pipe friction coefficient. Note that the American equivalent of the British term f is λ where $\lambda = 4f$.

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 (1.15×10^{-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 V [litres]	Time T [secs]	Flow rate Q [m³/s]	Pipe Diam. d [m]	Velocity u [m/s]	Reynolds Number Re	Measured Head Loss h [m H_2O]	Friction Coefficient f
		$\frac{V \times 10^{-3}}{T}$		$\frac{4Q}{\pi d^2}$	$\frac{\rho u d}{\mu}$	$(h_C - h_D)$	$\frac{g d h}{2 l u^2}$

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 m³/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 m² (d_0 = 14mm for the Venturi, 20mm for the orifice plate), A_1 is the area of the pipe upstream m² (d_1 = 24mm), Δh is the differential head in metres of water and g is the acceleration due to gravity in m/s².

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/s².

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 change in differential head. Estimate the average reading obtained and compare this with the maximum reading at the centre of the pipe.

Processing Results (for the Pitot tube)

All readings should be tabulated as follows:

Pitot Tube Position	Volume V [litres]	Time T [secs]	Flowrate Q [m³/s]	Pipe diameter d [m]	Pipe Area A [m²]	Velocity measured u_m [m/s]	Differential Head h [m H_2O]	Velocity calculated u_c [m/s]
			$\frac{V \times 10^{-3}}{T}$		$\frac{\pi d^2}{4}$	$\frac{Q}{A}$	$(h_C - h_D)$	$(2\ g\ h)^{0.5}$

Compare each calculated velocity with the measured velocity (determined from the volume flowrate and cross sectional area of the pipe).

What is the effect of the velocity profile on the results obtained?

Note: The Pitot tube is included for the purpose of demonstration only. The small differential head produced by the Pitot tube means that it should only be used in applications where high velocity is to be measured. Accuracy of measurement on the C6-MKII-10 will be poor because of the low water velocity.

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