armfield

Pipe Networks

Instruction Manual

C11-MKII

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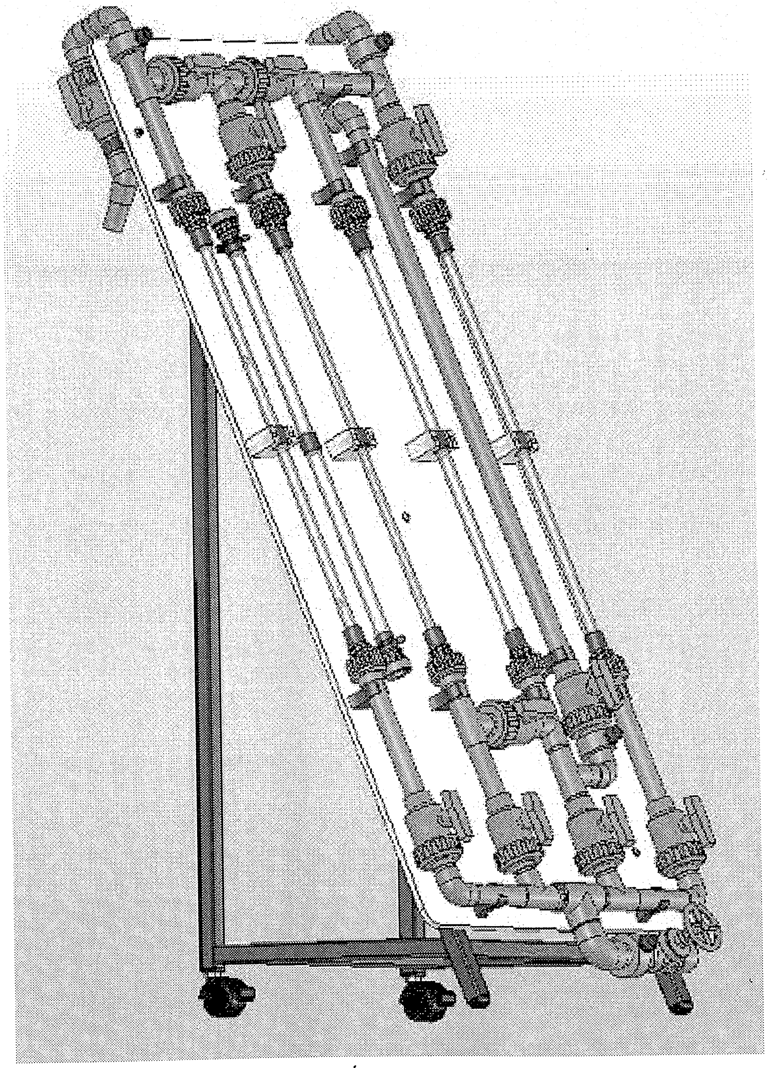
General Overview

Fluid mechanics has developed as an analytical discipline from the application of the classical laws of statics, dynamics and thermodynamics, to situations in which fluids can be treated as continuous media. The particular laws involved are those of the conservation of mass, energy and momentum and, in each application, these laws may be simplified in an attempt to describe quantitatively the behaviour of the fluid.

The Hydraulics Bench service module, F1-10, provides the necessary facilities to support a comprehensive range of hydraulic models each of which is designed to demonstrate a particular aspect of hydraulic theory.

The C11-MKII Pipe Network apparatus provides a simple low cost introduction to flow through interconnected pipes. Pipes of different inside diameters can be connected in series, in parallel and in a ring main configuration to demonstrate the head flow characteristics of water flowing through different pipe networks. A full description of the apparatus is given later in this manual.

Operation of the C11-MKII requires connection to a Hydraulics Bench Service unit F1-10.



C11-MKII Pipe Network Apparatus

A common problem in pipeline hydraulics is the determination of the flows and pressures (head losses) in a system of interconnected pipes, often known as a "pipe network". Such networks range from a single pipe to complex systems involving many pipes of different lengths and diameters, and incorporating distributed supply points. A town water supply is a good example of a very complex network. A good understanding of the behaviour of pipe networks and the ability to predict flow and pressure distributions are essential in the design of systems for the transportation of fluids. The Armfield C11-MKII Pipe Network apparatus is specifically designed to allow the setting up of a wide range of pipe arrays and the measurement of the flows and pressures using water as the fluid.

Measurement capabilities

- Measurement of head loss versus discharge for different sizes of pipes.
- Characteristics of flow through parallel pipe networks.
- Characteristics of flow through series pipe networks.
- Characteristics of flow around a ring main and the effect of changes in supplies and off-takes.
- Application of doubling pipes on existing networks to increase flowrate.

Equipment Diagrams

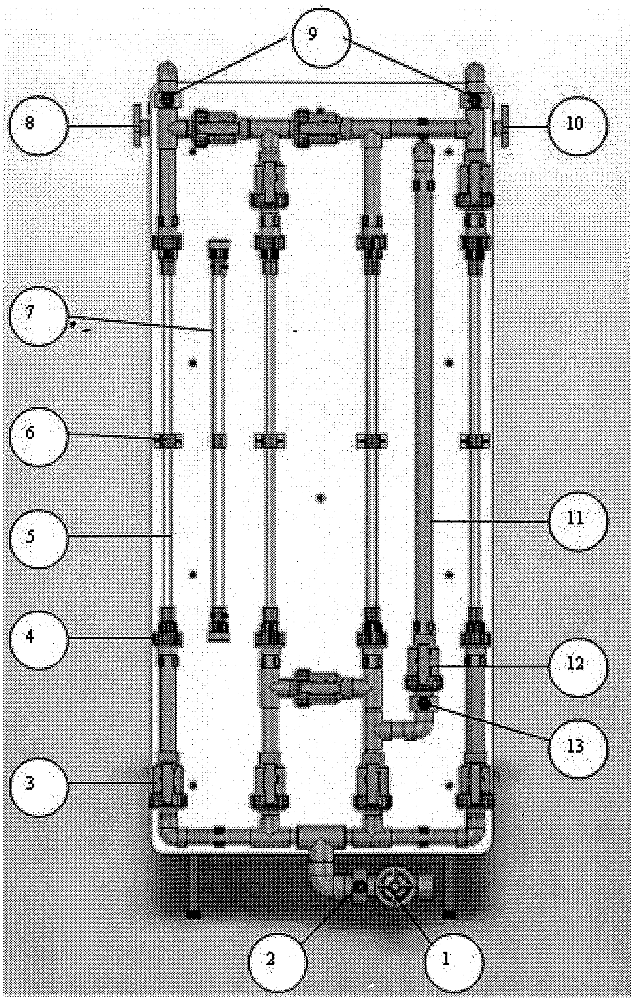


Figure 1: Front view of C11-MKII Pipe Network Apparatus

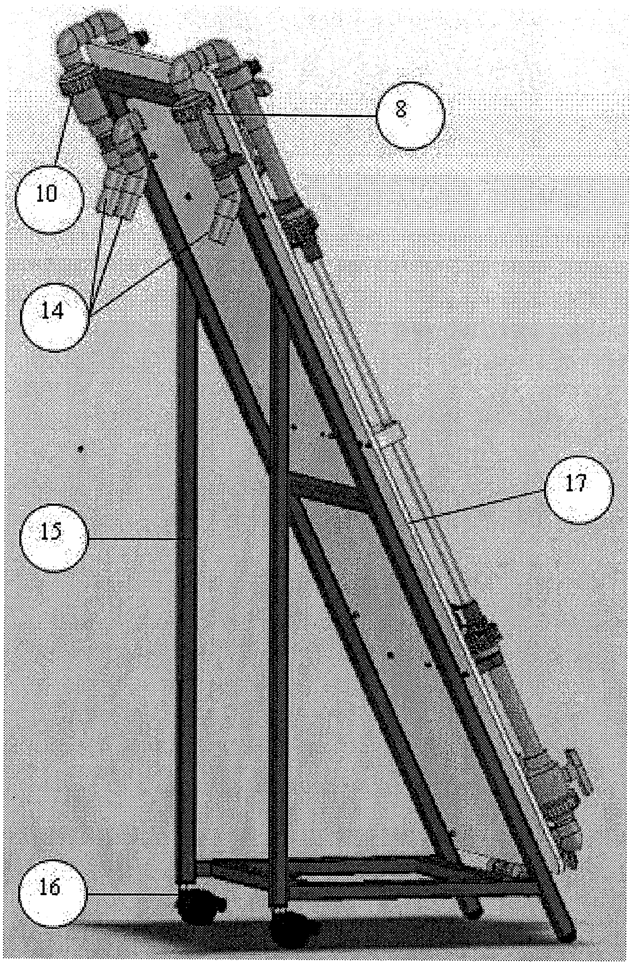


Figure 2: Rear view of C11-MKII Pipe Network Apparatus

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 **C11-MKII Pipe Network 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.

Electrical Safety

The equipment described in this Instruction Manual operates using a service unit (the F1-10 Hydraulics Bench) that is powered by a mains voltage electrical supply.

- The Pipe Network apparatus involves the use of water so the electrical supply to the F1-10 must be properly protected to minimise the possibility of electric shock.
- The F1-10 Hydraulics Bench must be operated as described in the F1-10 product manual, and must be tested regularly to ensure that the integral electrical protection is working correctly.

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.

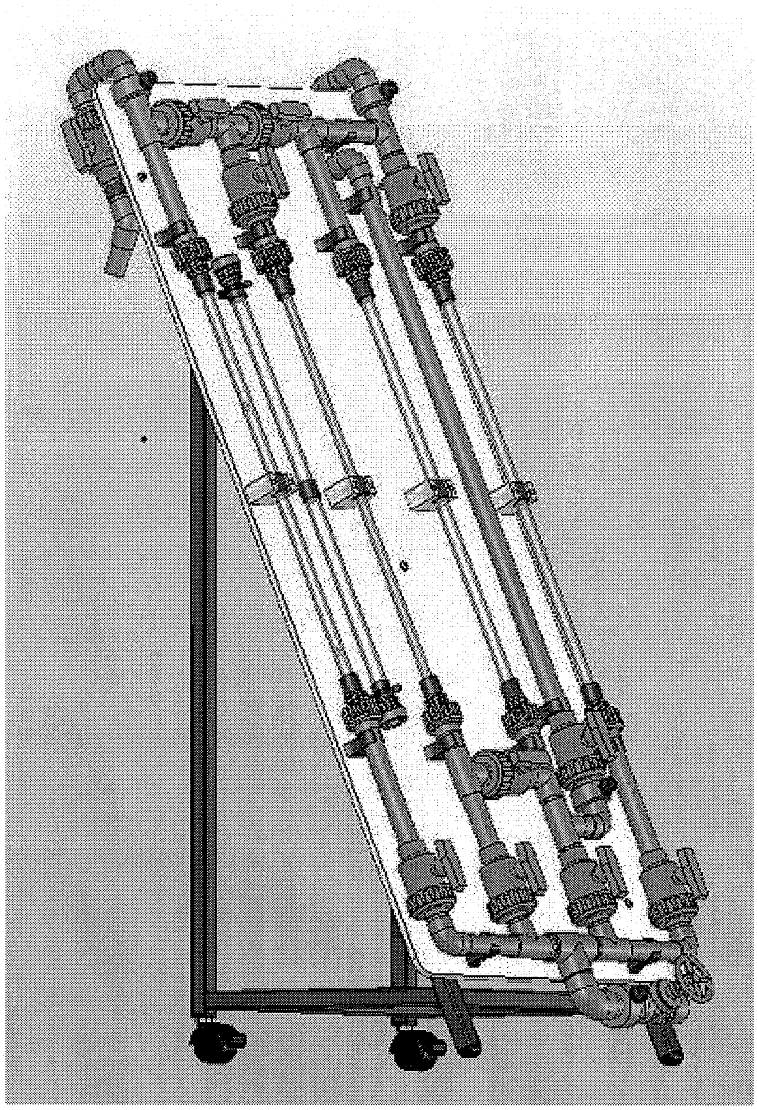
Overview

The permanent arrangement of PVC pipes and fittings is mounted on a freestanding support frame that is designed to stand alongside an F1-10 Hydraulics Bench in use. Connection to the F10-10 is via a reinforced flexible tube and threaded union with 'O' ring seal allowing connection to the F1-10 without the use of tools.

Isolating valves allow a wide range of different series, parallel and mixed pipe configurations to be created without draining the system. Flow into the network and flow out from the network at each outlet can be individually varied to change the characteristics of the system.

All straight test pipes are installed using threaded unions with 'O' ring seals that allow the pipes with different diameters to be repositioned without the use of tools.

Self-sealing quick release tappings at strategic points in the network allow rapid connection of the digital hand-held pressure meter, allowing appropriate differential pressures to be measured. Flow leaving any of the outlets in the network is measured using the volumetric facility incorporated on the F1-10 Hydraulics Bench.



C11-MKII Pipe Network Apparatus

The network of pipes and fittings is permanently mounted on a freestanding support frame that is designed to stand alongside an F1-10 Hydraulics Bench in use. The support frame consists of a painted steel frame (15) clad with a PVC panel (17) to which the various components are fitted. The rear legs of the frame incorporate castors (16) to aid mobility whereas the front legs sit on the floor. The unit can be easily moved to a different location by tilting the frame backwards to lift the front legs off the floor then moving the unit on its castors, similar to operating a sack truck.

Connection to the water outlet on F1-10 is via a flexible tube terminated in a union with an 'O' ring seal. The mating half of the union is screwed onto the outlet on F1-10 after removing the yellow quick release connector fitted to the F1-10. The other end of the flexible tube is connected to the inlet of the flow control valve (1) located at the bottom of the network of pipes. This connection also utilises a union with 'O' ring seal. The unions allow the flexible tube to be connected or disconnected without the use of tools.

The route that the water takes through the network of pipes and fittings is selected by opening and closing the appropriate isolating valves (3). This allows different configurations of pipes in series, pipes in parallel, doubling pipes, pipes in a ring main etc to be created for evaluation.

Four test pipes (5) are installed in the network and a spare pipe (7) is located in storage clips on the panel. A full range of exercises can be conducted using the four test pipes in their default positions (9 mm, 6 mm, 10 mm then 9 mm from left to right). All test pipes are installed using threaded unions with 'O' ring seals, at the top and bottom, that allows the pipes with different diameters to be repositioned without the use of tools, if required. The optional pipe with 14 mm bore can also be used in the network, if required. Each test pipe incorporates a collar that locates in a support bracket at mid height to protect the pipe from damage.

Appropriate differential pressures (head losses) are measured using the hand held pressure meter that is supplied with C11-MKII. The two flexible tubes attached to the pressure meter incorporate quick release fittings that connect to self-sealing quick release tappings (2, 9 & 13) at strategic points in the network. Each connection at the pressure meter incorporates a bleed valve. When opened, this valve allows water to flow through the flexible tubing forcing any trapped air out of the tubing. The pressure meter should be held over the volumetric tank on F1-10 when bleeding air from the connections.

Outflow from the network of pipes via the left hand outlet is varied using valve (8), outflow via the middle outlet is varied using valve (12) and outflow via the right hand outlet is varied using valve (10). The vertical pipe above valve (12) conveys water to a separate outlet at the top. The flow from any of the outlets can be measured using the volumetric facility on the F1-10.

The apparatus is designed with oversized fittings compared with the diameters of the test pipes so that head loss between pipes is small in comparison with the test pipes themselves. Typical losses associated with pipe fittings can be studied using different equipment such as the F1-22 Losses in Bends apparatus at elementary level or the C6-MKII Pipe friction apparatus that incorporates may different types of fittings.

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.

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

For details on filling and operating the F1-10 Hydraulics Bench refer to the Operation section.

For details on priming and operating the C11-MKII refer to the Operation section.

For details on priming and operating the hand held pressure meter supplied with C11-MKII refer to the Operation section.

Installation Process

The C11-MKII Pipe Network apparatus is supplied ready for use and only requires setting up as follows:

Carefully remove the unit from its packaging taking care not to damage the test pipes or the hand held pressure meter.

Locate the C11-MKII at the right hand end of an F1-10 Hydraulics Bench, positioned so that the three outlets at the top of C11-MKII will discharge into the side of the volumetric tank on the F1-10.

Connect the flexible supply tube to the union adjacent to the flow control valve at the bottom of the network of pipes. The union incorporates an 'O' ring seal and only needs to be hand tight (do not use a tool to tighten the fitting).

The unit is supplied with the test pipes fitted in the correct positions ready for testing and the optional test pipe is clipped to the support frame.

As the hand held pressure meter is portable this should be stored in a secure location until required for use.

When ready to check the operation of the unit and the hand held pressure meter refer to the Operation section.

Operation

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

Operating the Equipment

Connecting the C11-MKII to the F1-10 Hydraulics Bench

Locate the C11-MKII at the right hand end of the F1-10 Hydraulics Bench, positioned so that the four outlets at the top will discharge into the side of the volumetric tank on the F1-10.

Disconnect any accessory that is already connected to the quick release connector on the F1-10 (connector located inside the top moulded channel on the F1-10). Ensure that the F1-10 is switched off and the F1-10 flow control valve is closed then unscrew the quick release connector from the bed of the channel. Screw the adaptor, supplied with C11-MKII, onto the threaded outlet in the bed of the channel ensuring that the flexible sealing washer is fitted. Connect the flexible tube from the C11-MKII to the union on top of the adaptor. The union incorporates a 'O' ring seal and only needs to be hand tight (do not use a tool to tighten the fitting).

To restore the F1-10 to normal use; unscrew the union to disconnect the flexible tube then unscrew the adaptor from the threaded outlet in the bed of the channel on F1-10. Screw the quick release connector onto the threaded outlet to allow the F1-10 to be used with the appropriate accessories.

Filling the F1-10 Hydraulics Bench with water

Ensure that the drain valve in the sump tank (located in a cut-out at the bottom of the front on the F1-10) is fully closed.

Place a filling hose in the volumetric tank of the F1-10. Fill the sump tank with clean cold water by lifting the dump valve in the base of the volumetric measuring tank and allowing the water to drain from the volumetric at the actuator°tank into the sump tank. (When lifted, a twist of 90 will retain the dump valve in the open position.). When full ensure that the water level in the sump tank is just below the outlet in the bottom of the volumetric tank.

A few drops of wetting agent or surfactant should be added to the water in the sump tank to reduce the effect of surface tension. Note that too much wetting agent will cause foaming in the water.

Preparing the C11-MKII Pipe Network apparatus for use

Check that the C11-MKII is correctly positioned so that all three outlets will discharge into the volumetric tank on F1-10.

Check that the test pipes are correctly positioned for the required exercise. All exercises can be performed with a standard set up (pipes with bores of 9 mm, 6 mm, 10 mm and 9 mm from left to right). However, the pipes can be interchanged if required to obtain different network combinations and an alternative pipe with an inside diameter of 14 mm can also be substituted. The spare pipe is stored in clips on the support frame.

Before removing a test pipe ensure that the system is not pressurised then drain the water from the network by disconnecting the flexible supply pipe from the F1-10 and lowering it to a low level drain.

Carefully unscrew the unions at the top and bottom of the test pipe (Hold the smaller diameter still while rotating the large nut on each coupling to avoid twisting the test pipe). After unscrewing both unions, slide the large nut clear of the union then slide the test pipe forwards. Reinstalling a test pipe is simply the reverse of this procedure. Ensue that the test pipe is located in the support bracket at mid height then tighten the unions by hand (do not use hand tools to tighten the unions).

When the test pipes in the required positions reconnect the flexible supply tube to the F1-10 Hydraulics Bench.

Before using the apparatus for taking measurements it is sensible to prime all of the test pipes and interconnecting pipework to eliminate trapped air.

Close the flow control on the F1-10 then switch on the service pump. Gradually open the flow control valve on the F1-10 and check that all connections to the C11-MKII are leak tight.

Continue to open the valve on the F1-10 until fully open then open the flow control valve at the bottom of C11-MKII.

Open and close the isolating valves on C11-MKII as required to flush all air from the system.

When water flows continuously from all of the outlets the apparatus is primed and ready for use.

Operating the C11-MKII Pipe Network apparatus

Close the flow control on the F1-10 then switch on the service pump. Continue to open the valve on the F1-10 until fully open then open the flow control valve at the bottom of C11-MKII.

Open or close the isolating valves as required to obtain the required network.

The flowrate of the water flowing from each of the outlets can be measured using the volumetric tank on the F1-10. Refer to the F1-10 manual for details on using the volumetric tank.

After use, close the flow control valve on the F1-10 bench and switch off the service pump.

Refer to the suggested demonstrations for further information.

Connecting and Priming the Pressure Meter

The flexible tubes attached to the pressure meter are terminated with a male quick release connecter that can be coupled to any of the female tappings on the C11-MKII. This allows the differential pressure to be measured between any two selected tappings on the C11-MKII.

To obtain accurate readings on the pressure meter it is essential that the flexible tubes between the pipe network and the pressure meter are completely full of water and do not contain air bubbles. This is achieved as follows:

After priming the pipe network, as described previously, connect the pressure meter to the appropriate tappings on the network. Hold the pressure meter over the volumetric tank on F1-10 or a suitable container then open each bleed valve in turn until water flows continuously from the open valve. When all air bubbles have been expelled close the bleed valves then switch on the meter to take readings.

After disconnecting the pressure meter and reconnecting it to different tappings on the network, repeat the priming procedure to ensure accurate readings.

Note: When using the hand held pressure meter in conjunction with C11-MKII the range of the meter should be set to cmH_2O to indicate head loss directly rather than in units of pressure. The reading should be divided by 100 to give metres of H_2O when using the measured values in calculations.

To operate the meter press the On/Off button until the display appears then press the Range button until the units cmH_2O appears in the display. The meter is then ready to take measurements. After making an adjustment to the system, allow the conditions to settle before taking a reading. If readings fluctuate after allowing the system to settle, press the Filter button to dampen the readings.

For further details on using the hand held pressure meter refer to the instructions supplied with the meter.

Preparing the C11-MKII Pipe Network apparatus for storage

Switch off the F1-10 Hydraulics Bench then disconnect the flexible supply tube from the outlet on the F1-10 by unscrewing the coupling. Drain all water from the C11-MKII pipe Network apparatus by opening the flow control valve at the bottom, opening all of the isolating valves and directing the flexible supply hose to a low level drain so that the water drains.

Equipment Specifications

Overall Dimensions

Height - 1380 mm

Width - 785 mm

Depth - 656 mm

Specifications

Length of test pipes:	0.7 m
Nominal inside diameter of test pipes:	6 mm (1x)
	9 mm (2x)
	10 mm (1x)
	14.0 mm (1x)
Nominal inside diameter of manifolds:	22.4 mm
Differential pressure measurement:	Digital pressure meter (alternative units selectable)
Range:	0 – 2000 cmH_2O (0 – 2000 mBar)
Resolution:	1 cm H_2O (1 mBar)

C11-MKII requires the F1-10 Hydraulics Bench Service unit.

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

Little maintenance is required but it is important to drain all water from the C11-MKII Pipe Network apparatus and associated pipework when not in use.

Cleaning

If it is necessary to clean the outside of the equipment it should be wiped over with a damp cloth. Do not use solvents that will attack the PVC or other materials of construction and do not use abrasive cleaners.

Storage

Switch off the F1-10 Hydraulics Bench then disconnect the flexible supply tube from the outlet on the F1-10 by unscrewing the coupling. Drain all water from the C11-MKII pipe Network apparatus by opening the flow control valve at the bottom, opening all of the isolating valves and directing the flexible supply hose to a low level drain so that the water drains. The C11-MKII can then be moved to a suitable location for storage.

The rear legs of the frame incorporate castors to aid mobility whereas the front legs sit on the floor. The unit can be easily moved to a different location by tilting the frame backwards to lift the front legs off the floor then moving the unit on its castors, similar to operating a sack truck.

Note: For convenience in storage the flexible supply tube can be disconnected at the flow control valve on C11-MKII by unscrewing the union. Take care not to lose the 'O' ring seal.

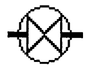
Laboratory Teaching Exercises

Index to Exercises

Nomenclature

Name	Unit	Symbol	Type	Definition
Inside Diameter of pipe	m	d	Constant	0.006 m, 0.008 m, 0.009 m, 0.010 m or 0.014 m as appropriate
Length of pipe	m	L	Constant	0.7 m for all test pipes
Volume collected	m^3	V	Measured	Volume of water collected in a known time period (t). **Note:** Convert to cubic metres for calculations (divide litres by 1000)
Time to collect	s	t	Measured	Time taken to collect a known volume of water (V)
Volume Flow Rate	m^3/s	Q_v	Calculated	$Q_v = \frac{V}{t} = \frac{\text{Volume collected}}{\text{Time to collect}}$
Friction Head Loss	m H_2O	H_f	Calculated	$H_f = K(\frac{LQ_v^2}{d^5})$
Friction constant		K	Empirical	
Head loss	m H_2O	H_x	Measured	Where x defines the measurement location
Total headloss – pipes in series	m H_2O	H_T	Calculated	$H_T = H_1 + H_2 + H_3$
Total flowrate – pipes in parallel	m H_2O	Q_T	Calculated	$Q_T = Q_1 + Q_2 + Q_3$

In the diagrams that accompany the exercises, the following symbols are used to identify if valves should be fully open, fully closed or adjusted as required to give the required flow.

 **Valve fully open**  **Valve fully closed**  **Flow Control Valve**

Exercise A - Flow through pipes with different diameters

Objective

To measure head loss versus discharge for water flowing through individual pipes with different internal diameters.

Method

By measuring the flowrate and corresponding head loss (pressure drop) across pipes with different inside diameters.

Equipment Required

In order to complete the demonstration the following equipment is required:

C11-MKII Pipe Network apparatus

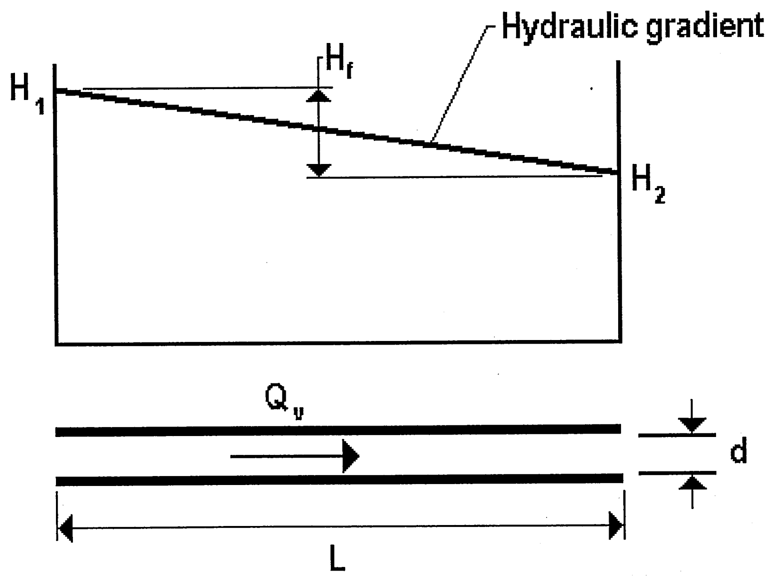
F1-10 Hydraulics Bench

Stop clock (not supplied by Armfield)

Optional Equipment

None

Theory



Any pipeline with diameter d and length L carrying a flow rate of Q will have a head loss H_f due to friction along its length that is defined by the equation:

$$H_f = K\left(\frac{LQ_v^2}{d^5}\right) \quad mH_2O$$

H_f = Head loss due to friction mH_2O

K = Constant — Dimensionless

L = Length of pipe — 0.7 m (constant)

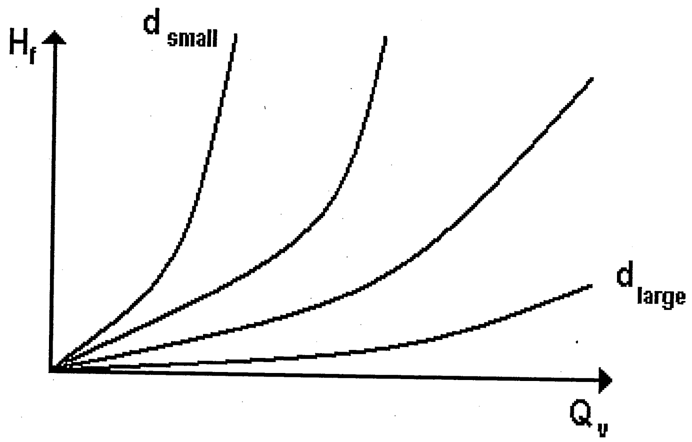
Q_v = Volumetric flowrate — m^3/s

D = Inside diameter of pipe — m (0.006, 0.009, 0.010 or 0.014 M as appropriate)

The actual Head Loss due to friction H_{1-2} can be measured using the hand held pressure meter so K can be determined from the equation

$$K = \frac{H_{1-2} d^5}{L Q_v^{\,2}}$$ (Dimensionless)

A graph of H_f against Q_v^2 will be similar to the diagram below showing increasing head loss with reducing pipe diameter and increasing flow.



Note: There will be additional losses in the pipework and fittings between the test pipes. These losses have been minimised on C11-MKII by using large diameter components in comparison with the bore of the test pipes. In a real application the losses from the fittings are likely to be more significant and it will be necessary to include these losses in any calculations.

Equipment Set Up

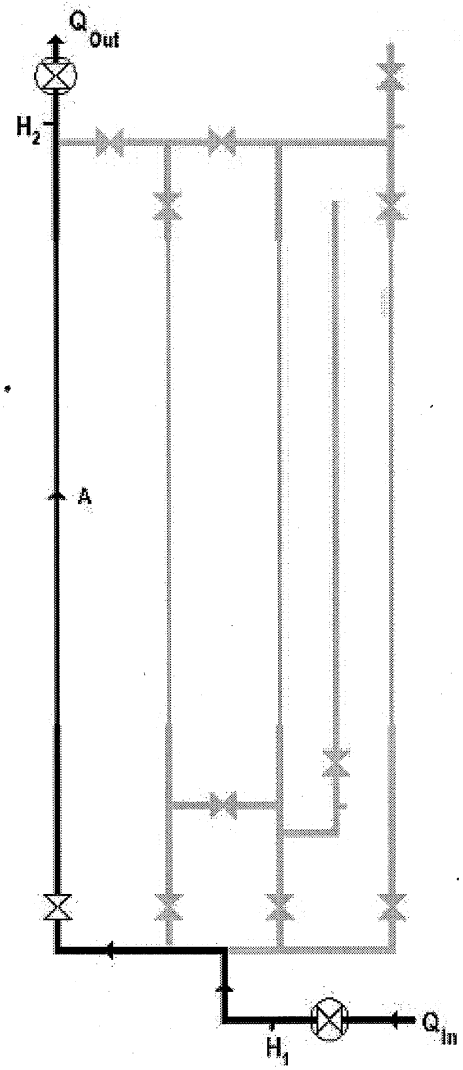
Configure the network on C11-MKII with the standard arrangement of test pipes, namely:

A = 9 mm, B = 6 mm, C = 10 mm and D = 9 mm from left to right, unless a different configuration is required.

Locate the C11-MKII at the right hand end of the F1-10 Hydraulics Bench, positioned so that the four outlets at the top will discharge into the side of the volumetric tank on the F1-10. If necessary refer to the Operating procedures section for details on how to connect and prime the F1-10 and C11-MKII.

Before using the apparatus for taking measurements it is essential to prime all of the test pipes and interconnecting pipework to eliminate trapped air.

Procedure

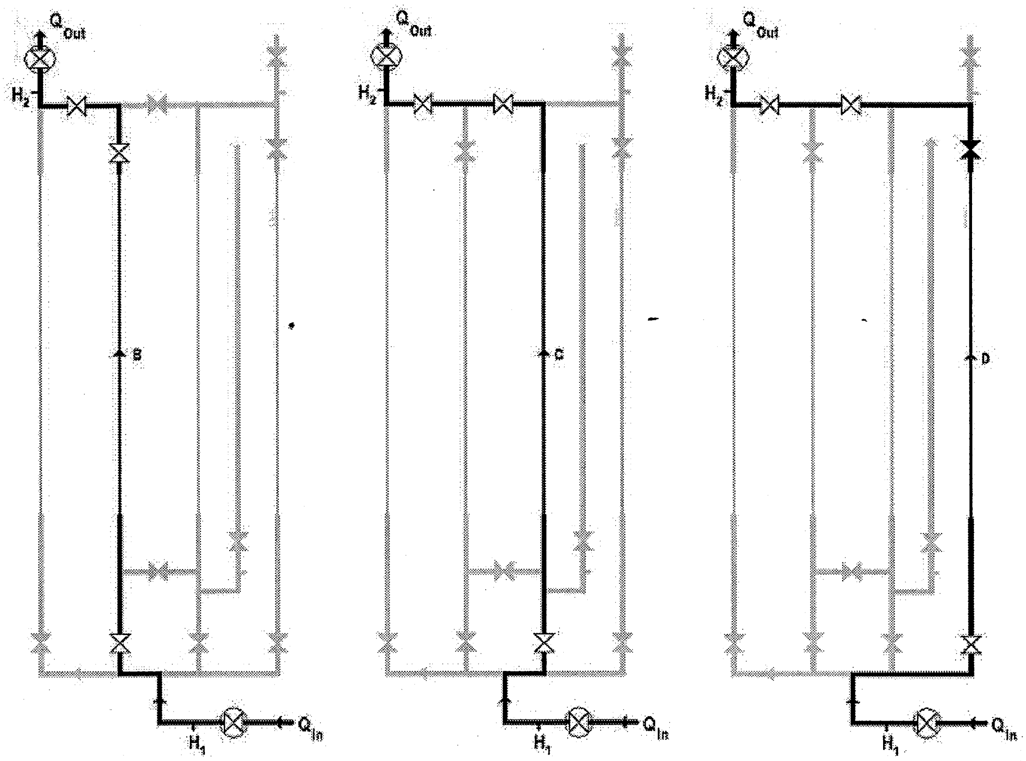


Ensure that all of the pipework is fully primed then configure the system to allow testing of pipe A by opening and closing the appropriate isolating valves as shown in the diagram to the right.

Open the inlet flow control valve at the base fully, ensure that the system is fully primed then connect the hand held pressure meter to tappings H_1 and H_2 to measure the head loss across pipe A. Before taking readings the pressure meter should be primed by holding the meter over the volumetric tank on F1-10 then opening the bleed valves at the connection to the meter until all air has been expelled from the flexible tubing to the meter.

Vary the flow through the test pipe from zero to maximum flowrate by adjusting the outlet flow control valve at the top or the inlet flow control valve at the bottom as convenient. At each setting allow the conditions to settle then measure and record the head loss using the hand held pressure meter and the corresponding flowrate using the volumetric tank on F1-10 with a stop clock.

When a head versus flow characteristic has been obtained for test pipe A reconfigure the isolating valves for test pipe B as shown below then repeat the procedure. Repeat this for test pipes C and D in turn.



For each test pipe create a table of measurements and for each run calculate a value of K as follows:

Test	Pipe Bore d m	Pipe Length L m	Head loss H_{1-2} mH_2O	Volume collected V m^3	Elapsed Time t secs	Flow Rate Q_v m^3/sec	K $\frac{H_f d^5}{L Q_v^2}$
1		0.7	0	0	0	0	0
2		0.7					
3		0.7					
4		0.7					
5		0.7					
6		0.7					

Note all measurements converted to metres for purposes of calculation.

Results

Compare the values obtained for K with the same diameter pipe at different flowrates and different diameter pipes at the same flowrate.

On a common chart draw graphs of head loss against flowrate for each of the test pipes so that the characteristics can be compared.

Note: Care should be taken when plotting the curves as these will be used for the analysis of later exercises involving head and flow relationships of pipes in parallel, pipes in series, pipes arranged in a ring main and doubling pipes.

Conclusion

Your results should confirm that head loss increases with the square of the velocity in a pipe i.e. for the same pipe, doubling the velocity increases the head loss by a factor of four times.

Your results should also confirm that for the same flowrate, increasing the diameter of a pipe reduces the velocity with a resulting drop in head loss.

Exercise B - Flow through pipes connected in parallel

Objective

To measure head loss versus discharge for water flowing through pipes with different internal diameters that are connected in parallel.

Method

By measuring the flowrate and corresponding head loss (pressure drop) across different combinations of pipes in parallel then comparing the loss with the predicted loss from the individual pipes at the same flowrate.

Equipment Required

In order to complete the demonstration the following equipment is required:

C11-MKII Pipe Network apparatus

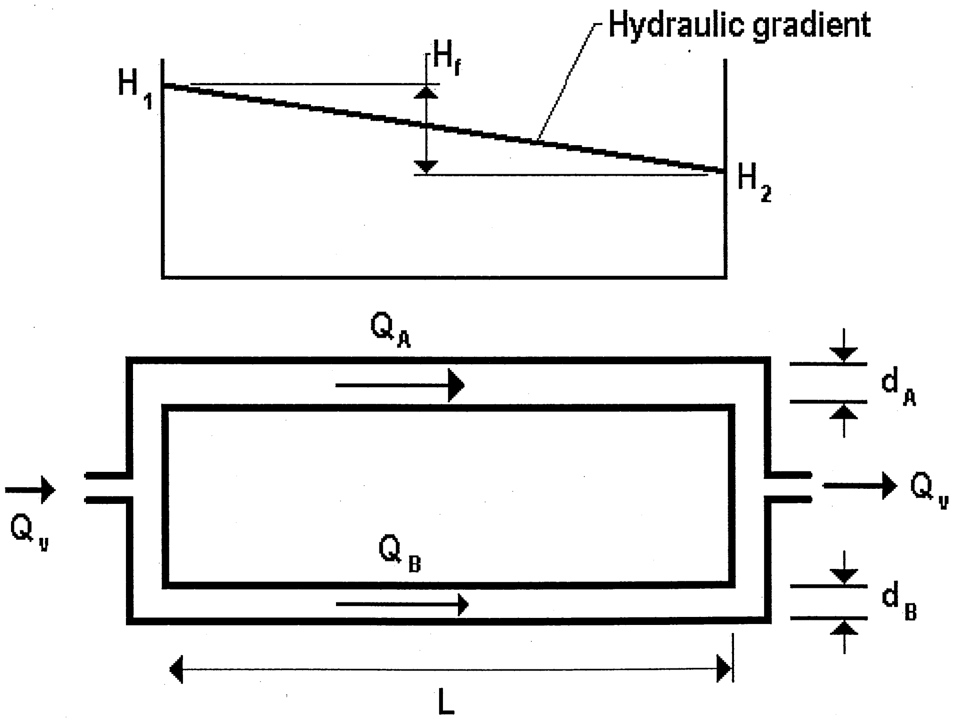
F1-10 Hydraulics Bench

Stop clock (not supplied by Armfield)

Optional Equipment

None

Theory



In a pipe network consisting of pipes of various diameters in parallel with each other, the pressure in the common manifolds, at the junction of the pipes, must be the same for all of the pipes. I.e. H_f is the same for each of the pipes. The total flow Q_V

therefore distributes itself between the individual pipes in accordance with the controlling end pressures and:

$Q_T = Q_A + Q_B$ for two pipes in parallel

$Q_T = Q_A + Q_B + Q_C$ for three pipes in parallel

$Q_T = Q_A + Q_B + Q_C + Q_D$ for four pipes in parallel

Note: There will be additional losses in the pipework and fittings between the test pipes. These losses have been minimised on C11-MKII by using large diameter components in comparison with the bore of the test pipes. In a real application the losses from the fittings are likely to be more significant and it will be necessary to include these losses in any calculations. On the C11-MKII all four test pipes are the same length. In a practical application the pipe lengths may vary.

Equipment Set Up

Configure the network on C11-MKII with the standard arrangement of test pipes, namely:

A = 9 mm, B = 6 mm, C = 10 mm and D = 9 mm from left to right, unless a different configuration is required.

Locate the C11-MKII at the right hand end of the F1-10 Hydraulics Bench, positioned so that the four outlets at the top will discharge into the side of the volumetric tank on the F1-10. If necessary refer to the Operating procedures section for details on how to connect and prime the F1-10 and C11-MKII.

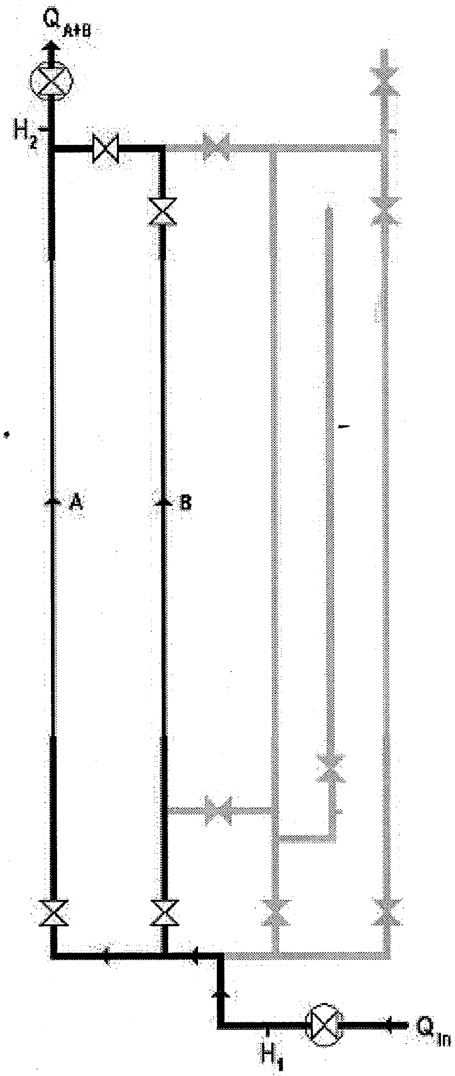
Before using the apparatus for taking measurements it is essential to prime all of the test pipes and interconnecting pipework to eliminate trapped air.

Procedure

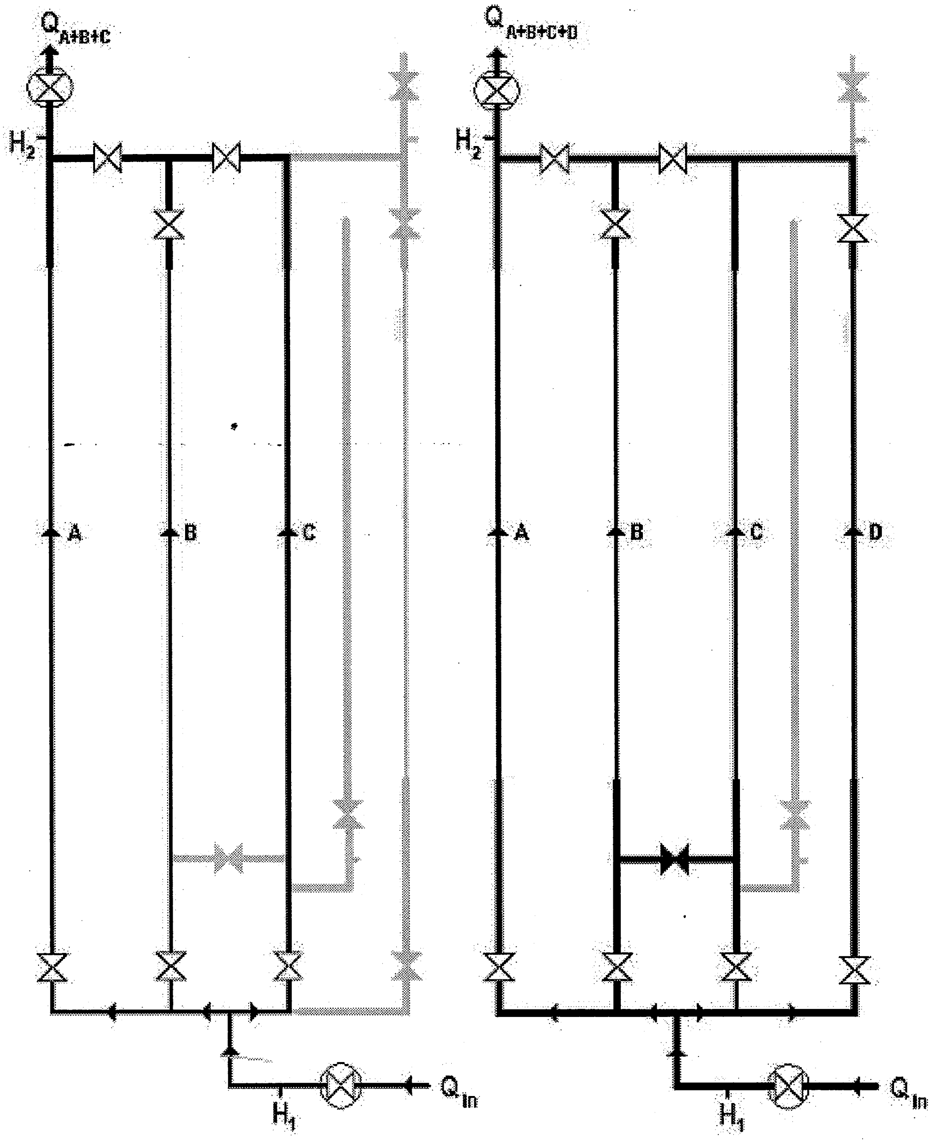
Ensure that all of the pipework is fully primed then configure the system to allow testing of pipes A and B in parallel by opening and closing the appropriate isolating valves as shown in the diagram to the right.

Open the inlet flow control valve at the base fully, ensure that the system is fully primed then connect the hand held pressure meter to tappings H_1 and H_2 to measure the head loss across pipes A and B in parallel. Before taking readings the pressure meter should be primed by holding the meter over the volumetric tank on F1-10 then opening the bleed valves at the connection to the meter until all air has been expelled from the flexible tubing to the meter.

Vary the flow through the test pipes from zero to maximum flowrate by adjusting the outlet flow control valve at the top or the inlet flow control valve at the bottom as convenient. At each setting allow the conditions to settle then measure and record the head loss using the hand held pressure meter and the corresponding flowrate using the volumetric tank on F1-10 with a stop clock.



Repeat these measurements with the network of pipe configured for three pipes in parallel then four pipes in parallel as shown in the diagram below:



Results

For each set of readings construct a table as follows:

Test	Pipe Bores d m	Head loss H_{1-2} mH_2O	Volume collected V m^3	Elapsed Time t secs	Measured Flow Q_v m^3/sec	Calculated Flow Q_v m^3/sec
1		0	0	0	0	0
2						
3						
4						
5						
6						

Note all measurements converted to metres for purposes of calculation.

Note: The calculated flow in the table is the sum of the flows through the individual pipes concerned. These flows cannot be measured directly and are obtained from the calibration curve for each individual size of pipe obtained in exercise A. The individual flow rate can be obtained by entering the measured head loss on the appropriate graph.

The flow in each of the pipes should be added together and the result compared to the total flow measured using the hydraulic bench.

Conclusion

Comment on the correlation between the total flow rate determined by measurement and by calculation from the individual flowrates determined by head loss. Account for any differences.

Comment on the magnitude of the flow rates in each of the pipes and account for their respective differences.

Advanced students should calculate the theoretical flow rate in any pipe for a given head difference from a knowledge of the pipe geometry and an estimated pipe friction factor. The values obtained should be compared to the experimentally determined values.

Suggest practical situations where parallel pipe networks might be found.

Exercise C - Flow through pipes connected in series

Objective

To measure head loss versus discharge for water flowing through pipes with different internal diameters that are connected in series.

Method

By measuring the flowrate and corresponding head loss (pressure drop) across pipes with different inside diameters.

Equipment Required

In order to complete the demonstration the following equipment is required:

C11-MKII Pipe Network apparatus

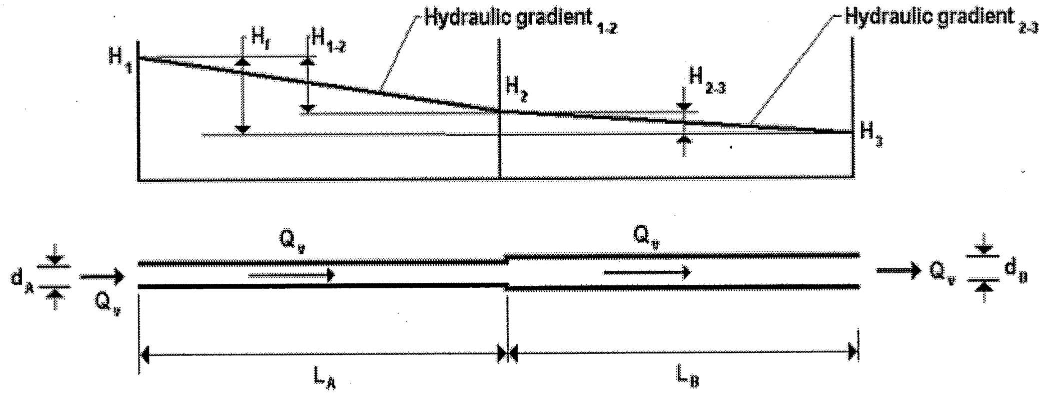
F1-10 Hydraulics Bench

Stop clock (not supplied by Armfield)

Optional Equipment

None

Theory



In a pipe network consisting of pipes of various diameters in series with each other, the same total flow Q_v must pass through each of the pipes in turn. The velocity in each section of pipe will vary, depending on the diameter, so the head loss will vary. Where pipe lengths differ, the head loss will also be affected. A flow Q_v through the series network will have a total head loss H_f along the whole length which is the sum of the losses in each of the individual pipes.

For example

$H_f = H_{1-2} + H_{2-3}$ for two pipes in series

$H_f = H_{1-2} + H_{2-3} + H_{3-4}$ for three pipes in series

Note: There will be additional losses in the pipework and fittings between the test pipes. These losses have been minimised on C11-MKII by using large diameter components in comparison with the bore of the test pipes. In a real application the losses from the fittings are likely to be more significant and it will be necessary to include these losses in any calculations.

Equipment Set Up

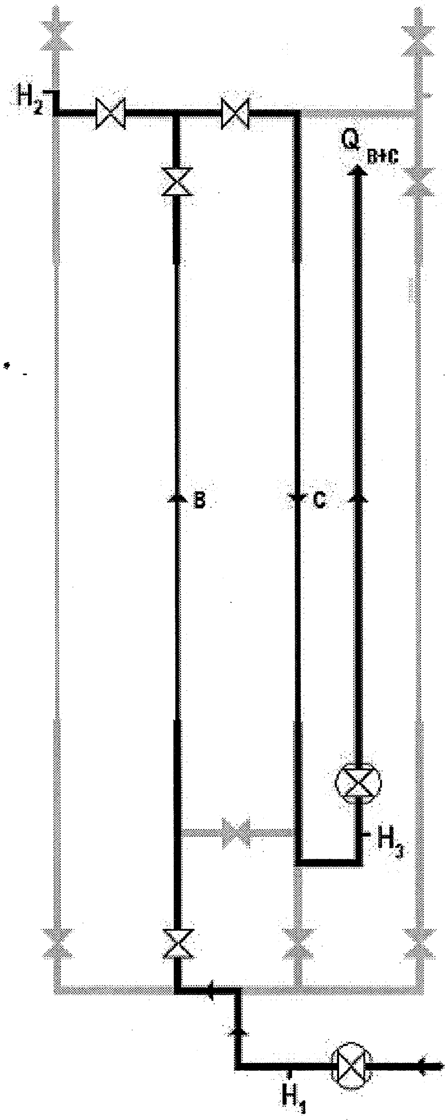
Configure the network on C11-MKII with the standard arrangement of test pipes, namely:

A = 9 mm, B = 6 mm, C = 10 mm and D = 9 mm from left to right, unless a different configuration is required.

Locate the C11-MKII at the right hand end of the F1-10 Hydraulics Bench, positioned so that the four outlets at the top will discharge into the side of the volumetric tank on the F1-10. If necessary refer to the Operating procedures section for details on how to connect and prime the F1-10 and C11-MKII.

Before using the apparatus for taking measurements it is essential to prime all of the test pipes and interconnecting pipework to eliminate trapped air.

Procedure



Ensure that all of the pipework is fully primed then configure the system to allow testing of pipes B and C in series by opening and closing the appropriate isolating valves as shown in the diagram to the right.

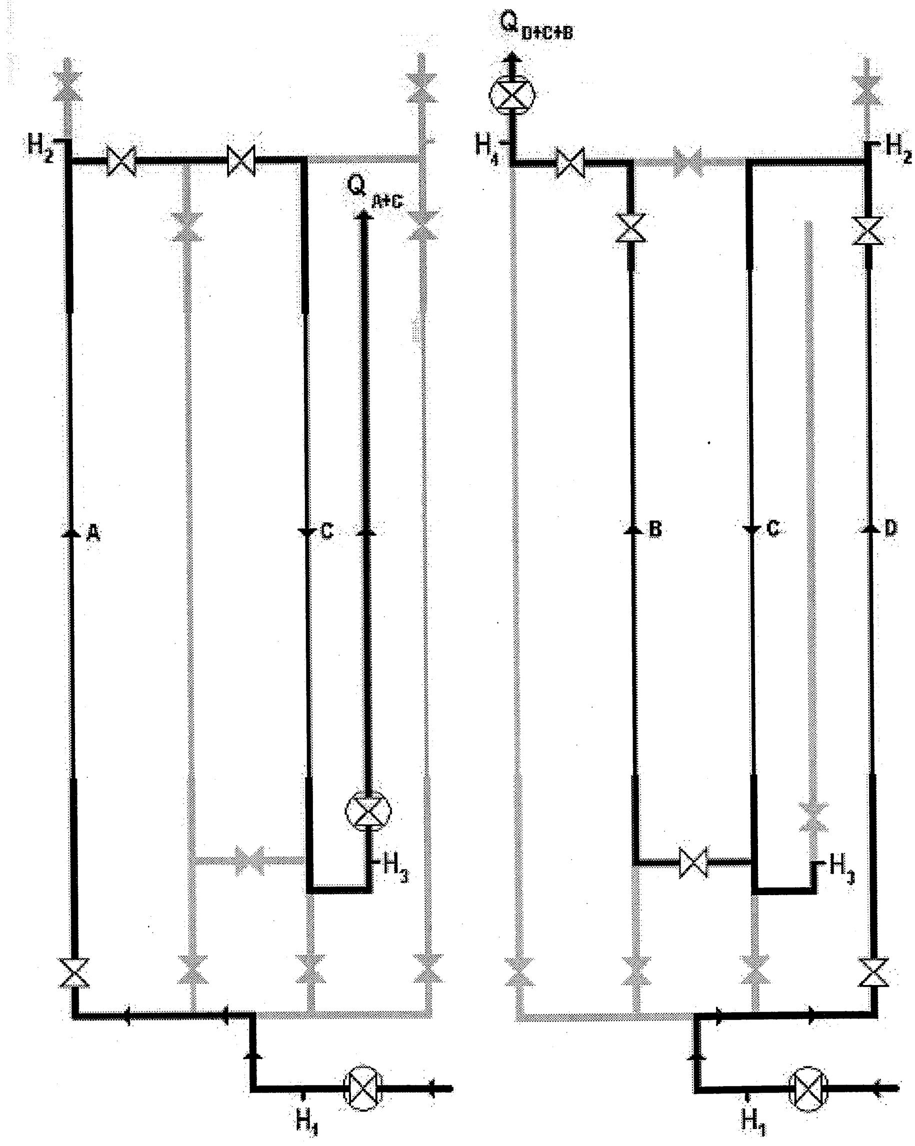
Open the inlet flow control valve at the base fully, ensure that the system is fully primed then connect the hand held pressure meter to tappings H_1 and H_3 to measure the head loss across pipes B and C in series. Before taking readings the pressure meter should be primed by holding the meter over the volumetric tank on F1-10 then opening the bleed valves at the connection to the meter until all air has been expelled from the flexible tubing to the meter.

Adjust the outlet flow control valve at the top or the inlet flow control valve at the bottom as convenient to give a low flow through the network then measure and record the head loss using the hand held pressure meter and the corresponding flowrate using the volumetric tank on F1-10 with a stop clock.

Before making any adjustments to the flowrate etc. reconnect the hand held pressure meter to tappings H_1 and H_2 to measure the head loss across pipe B only. The meter can also be connected to tappings H_2 and H_3 if required to prove that the head loss across pipe C is the difference between the measured losses across pipe B only and pipes B + C in series.

Vary the flow through the test pipes from zero to maximum flowrate by adjusting the outlet flow control valve at the top or the inlet flow control valve at the bottom as convenient. At each setting allow the conditions to settle then measure and record the head losses as before using the hand held pressure meter and the corresponding flowrate using the volumetric tank on F1-10 with a stop clock.

Repeat these measurements with the network of pipe configured for two alternative pipes in series then three pipes in series as shown in the diagram below.



Results

Test	Pipe Bores d m	Pipe Length L m	Head loss H_{1-2} mH_2O	Head loss H_{2-3} mH_2O	Head loss H_{3-4} mH_2O	Volume V m^3	Elapsed Time t secs	Flow Rate Q_v m^3/sec	Total Head loss H_f mH_20
1		0.7	0	0	0	0	0	0	0
2		0.7							
3		0.7							
4		0.7							
5		0.7							
6		0.7							

Note all measurements converted to metres for purposes of calculation.

Conclusion

From the results obtained confirm that the total head loss across the series network H_f is equal to the sum of the head losses in the individual pipes for all flow rates.

Comment on the magnitude of the individual head losses and account for the differences despite the flow through each being identical.

Advanced students should calculate the theoretical head loss in any section for a given flow from knowledge of the pipe geometry and an estimated pipe friction factor. The values obtained should be compared to the experimentally determined values.

Why is knowledge of the energy degradation in a pipe network of importance to a system designer? Suggest practical situations where series pipe networks might be found.

Exercise D - Flow through pipes connected in a ring main

Objective

To measure head loss versus discharge for water flowing through parallel pipes with different internal diameters.

Method

By measuring the flowrate and corresponding head loss (pressure drop) across pipes with different inside diameters.

Equipment Required

In order to complete the demonstration the following equipment is required:

C11-MKII Pipe Network apparatus

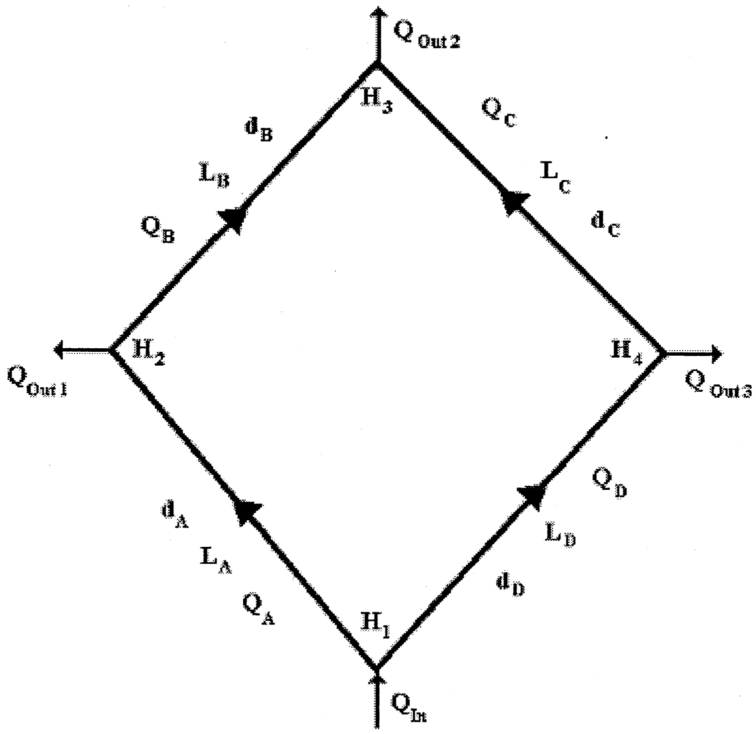
F1-10 Hydraulics Bench

Stop clock (not supplied by Armfield)

Optional Equipment

None

Theory



Solving any problem involving a ring main requires complex analysis of the head at each of the junctions and the flow through each of the individual pipes in the ring main, where all variables interact. For example, a reduction in flow at one outlet will affect the head loss in the pipes supplying water to it with a resulting change in flow to other parts of the network.

At any junction in the ring main the algebraic sum of the flows to or from the junction must be zero (the flow is positive or negative depending on the direction of flow).

For example in the diagram:

$Q_{in} + Q_A + Q_D = 0$ where flows Q_a and Q_d are negative because the flow is away from the junction

There will be additional losses in the pipework and fittings between the test pipes. These losses have been minimised on C11-MKII by using large diameter components in comparison with the bore of the test pipes. In a real application the losses from the fittings are likely to be more significant and it will be necessary to include these losses in any calculations.

Equipment Set Up

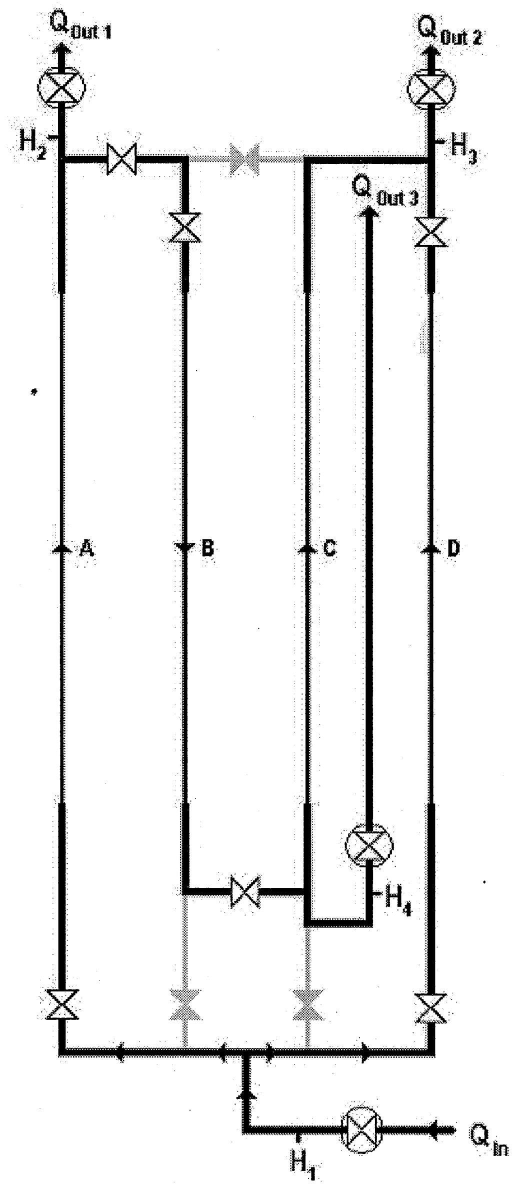
Configure the network on C11-MKII with the standard arrangement of test pipes, namely:

A = 9 mm, B = 6 mm, C = 10 mm and D = 9 mm from left to right, unless a different configuration is required.

Locate the C11-MKII at the right hand end of the F1-10 Hydraulics Bench, positioned so that the four outlets at the top will discharge into the side of the volumetric tank on the F1-10. If necessary refer to the Operating procedures section for details on how to connect and prime the F1-10 and C11-MKII.

Before using the apparatus for taking measurements it is essential to prime all of the test pipes and interconnecting pipework to eliminate trapped air.

Procedure



Ensure that all of the pipework is fully primed then configure the system to allow testing of pipes A, B, C and D in a ring main by opening and closing the appropriate isolating valves as shown in the diagram to the right.

Open the inlet flow control valve at the base fully, ensure that the system is fully primed then connect the hand held pressure meter to tappings H_1 and H_2 to measure the head loss across pipe A. Before taking readings the pressure meter should be primed by holding the meter over the volumetric tank on F1-10 then opening the bleed valves at the connection to the meter until all air has been expelled from the flexible tubing to the meter.

Adjust the three outlet flow control valves at the top to give a low flow through the network then measure and record the head loss H_{1-2} using the hand held pressure meter and the corresponding flowrates using the volumetric tank on F1-10 with a stop clock (to measure the flow from individual outlets direct the flow from the other outlets to the overflow in the side wall of the volumetric tank).

Before making any adjustments to the flowrate etc. reconnect the hand held pressure meter to tappings H_2 and H_4 then H_4 and H_3 then H_3 and H_1 to measure the head loss across the individual pipes.

Vary the flow through the pipe network by adjusting the outlet flow control valves at the top in different combinations to give different flows in different parts of the ring main. At each setting allow the conditions to settle then measure and record the head losses as before using the hand held pressure meter and the corresponding flowrates using the volumetric tank on F1-10 with a stop clock.

Leave the three outlet control valves fixed then perform one run with the inlet flow control valve throttled to give reduced flow.

Results

For each configuration construct tables of measured and calculated values as follows:

Vol Q_{out1} litres	Time Q_{out1} secs	Flow Q_{out1} m^3/s	Vol Q_{out2} litres	Time Q_{out2} secs	Flow Q_{out2} m^3/s	Vol Q_{out3} litres	Time Q_{out3} secs	Flow Q_{out3} m^3/s	Flow Q_{in} m^3/s

Where Q_{in} is the sum of Q_{out1} + Q_{out2} + Q_{out3}

Using the calibration data obtained in exercise A estimate the flow through each test pipe base on the head loss then complete the following table. The direction of flow is indicated by the direction of the fall in head.

Pipe	Pipe Bore d m	Measured Head loss mH_2O	Estimated Flow Rate m^3/sec	Sum of flows at junction A/B	Sum of flows at junction B/C	Sum of flows at junction C/D	Sum of flows at junction D/A
A							
B							
C							
D							

Note all measurements converted to metres for purposes of calculation.

Advanced students may wish to analyse the ring main theoretically and predict the flow and head distribution from knowledge of ring geometry and basic assumptions regarding pipe friction factors and inlet conditions. Several methods are available, some using techniques of successive approximation.

Conclusion

Confirm that net zero flow is obtained at each junction in the network and comment on any discrepancies.

Comment on the variations in the network when the flow is changed at any of the outlets.

Comment on the variation in the network when the flow into the network is varied.

Comment on the distribution of the flow around the ring main and suggest practical situations for the use of ring mains.

Comment on the difficulty of analysing the flows around and through a typical network with varying inflow and varying outflows.

Exercise E - Using doubling pipes to increase capacity of a pipeline

Objective

To show how the flow carrying capacity of a pipeline is increased when the pipe is doubled for part of its length.

Method

By measuring the flowrate and corresponding head loss (pressure drop) across two pipes in series then one pipes doubled.

Equipment Required

In-order to complete the demonstration the following equipment is required:

C11-MKII Pipe Network apparatus

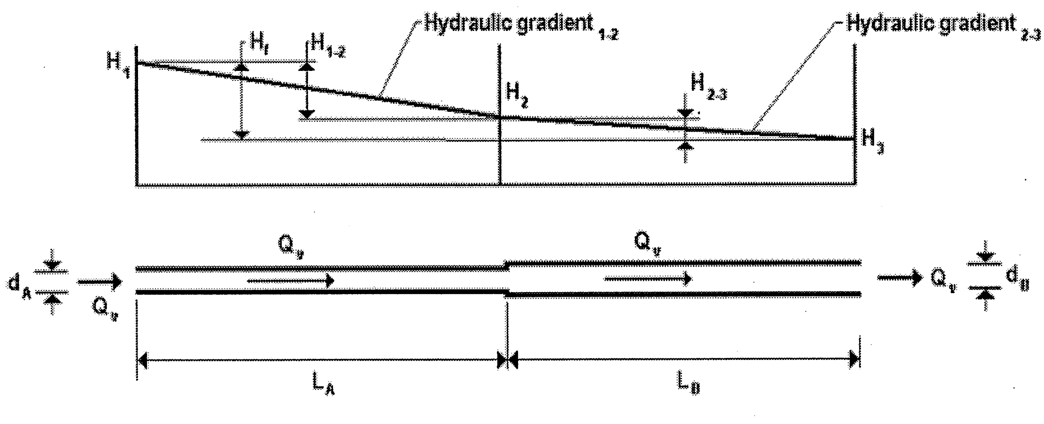
F1-10 Hydraulics Bench

Stop clock (not supplied by Armfield)

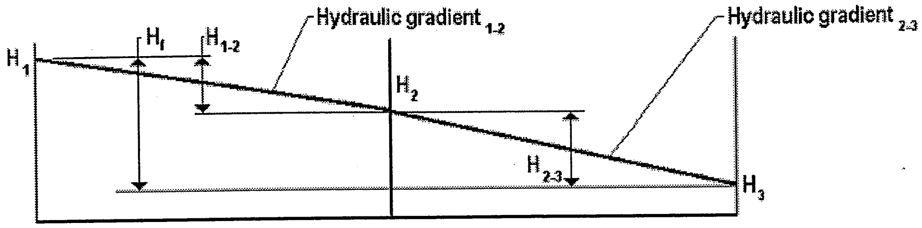
Optional Equipment

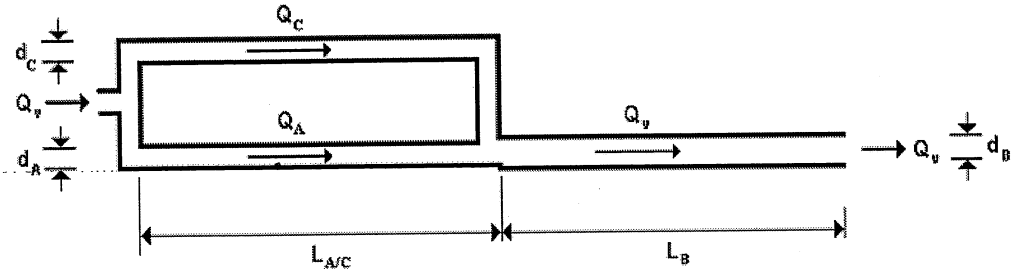
None

Theory

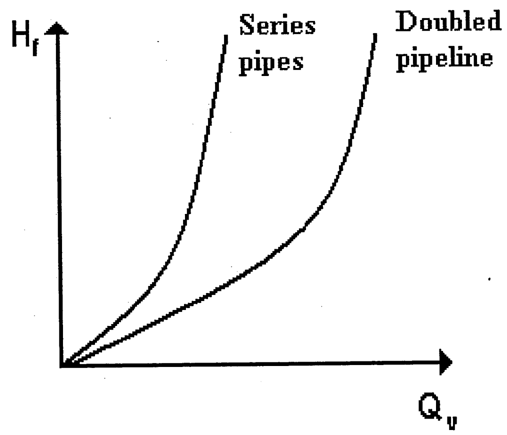


Two pipes connected in series





Left hand pipe doubled to reduce head loss



In order to increase the flow carrying capacity, a pipeline can be replaced with a pipe having larger diameter or a parallel pipe could be added as described in exercise B. However, this is likely to be very expensive and may not be practicable because of the location of the pipeline.

An improvement can be effected by adding a parallel pipe over part of the pipe line, especially if [part of the pipeline is smaller in diameter than the rest. This additional pipe is called a doubling pipe.

The original pipe line is a series arrangement as described in exercise C. The addition of the doubling pipe creates a parallel section in series as shown in the diagram.

At a given flow rate, the head loss across pipe B is unaffected because the flow through this pipe remains the same. But the flow through pipe A is now shared with pipe C reducing the head loss in this section. Since most systems are dependent on the head available (from a reservoir or from a circulating pump), the reduction in head loss means that more water can flow through the doubled pipe arrangement.

There will be additional losses in the pipework and fittings between the test pipes. These losses have been minimised on C11-MKII by using large diameter components in comparison with the bore of the test pipes. In a real application the losses from the fittings are likely to be more significant and it will be necessary to include these losses in any calculations.

Equipment Set Up

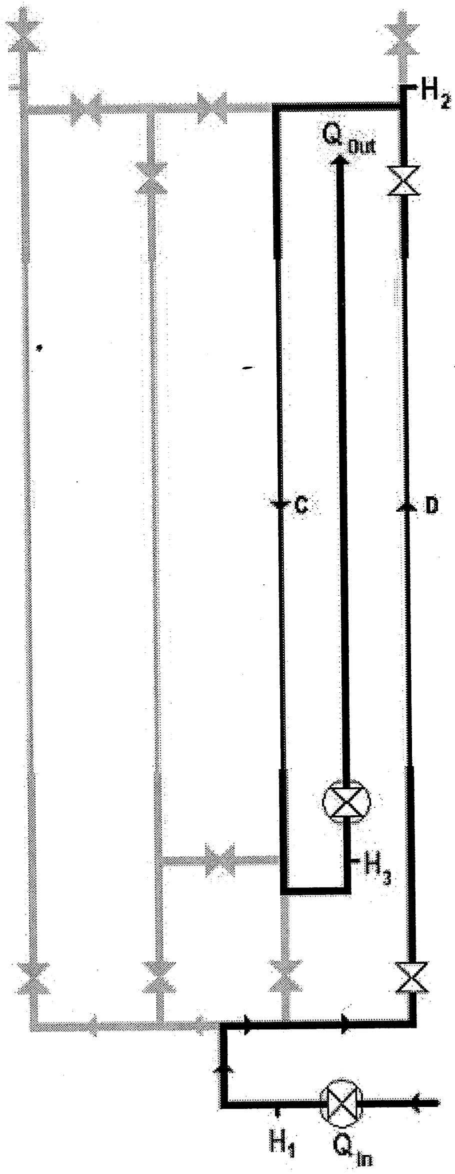
Configure the network on C11-MKII with the standard arrangement of test pipes, namely:

A = 9 mm, B = 6 mm, C = 10 mm and D = 9 mm from left to right, unless a different configuration is required.

Locate the C11-MKII at the right hand end of the F1-10 Hydraulics Bench, positioned so that the four outlets at the top will discharge into the side of the volumetric tank on the F1-10. If necessary refer to the Operating procedures section for details on how to connect and prime the F1-10 and C11-MKII.

Before using the apparatus for taking measurements it is essential to prime all of the test pipes and interconnecting pipework to eliminate trapped air.

Procedure



Ensure that all of the pipework is fully primed then configure the system to allow testing of pipes D and C in series by opening and closing the appropriate isolating valves as shown in the diagram to the right.

Open the inlet flow control valve at the base fully, ensure that the system is fully primed then connect the hand held pressure meter to tappings H_1 and H_3 to measure the head loss across pipes D and C in series. Before taking readings the pressure meter should be primed by holding the meter over the volumetric tank on F1-10 then opening the bleed valves at the connection to the meter until all air has been expelled from the flexible tubing to the meter.

Adjust the outlet flow control valve at the top or the inlet flow control valve at the bottom as convenient to give a low flow through the network then measure and

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