Experiment – 3 Hydraulics Bench Experiment

Aim of this Experiment

The hydraulic bench experiment allows the examination of pressure losses in different diameter straight length pipes, demonstration of the pressure drop across a sudden constriction and demonstration of pressure drop in short and long elbows.

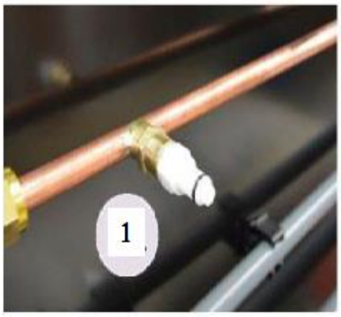
Experimental Set – up

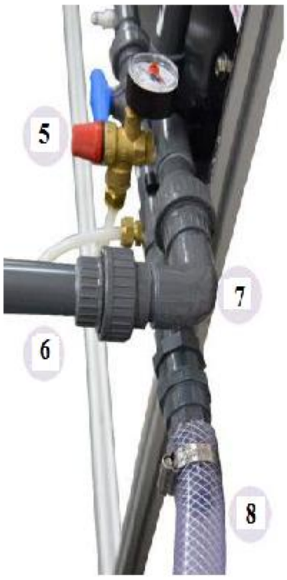
The HB100 is an essential item needed for the experimental use of the majority of the HB100 range. It features a large capacity **water tank** and a powerful centrifugal **pump** that can deliver a continuous recirculated water supply to the various modules within the range. A flow **return pipe**and **extension tube**allows the bench to be run without an optional module affixed to its top surface and ensure any water splashing is avoided.

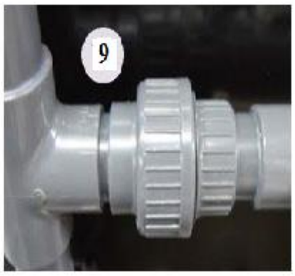
The unit is to be used in the laboratory and requires a source of water and drain. These are required to initially fill the **water tank** and for occasional changing of the **tank** water. After placing the unit in its intended location then**4wheels** should be lockedby operating the foot brakes.

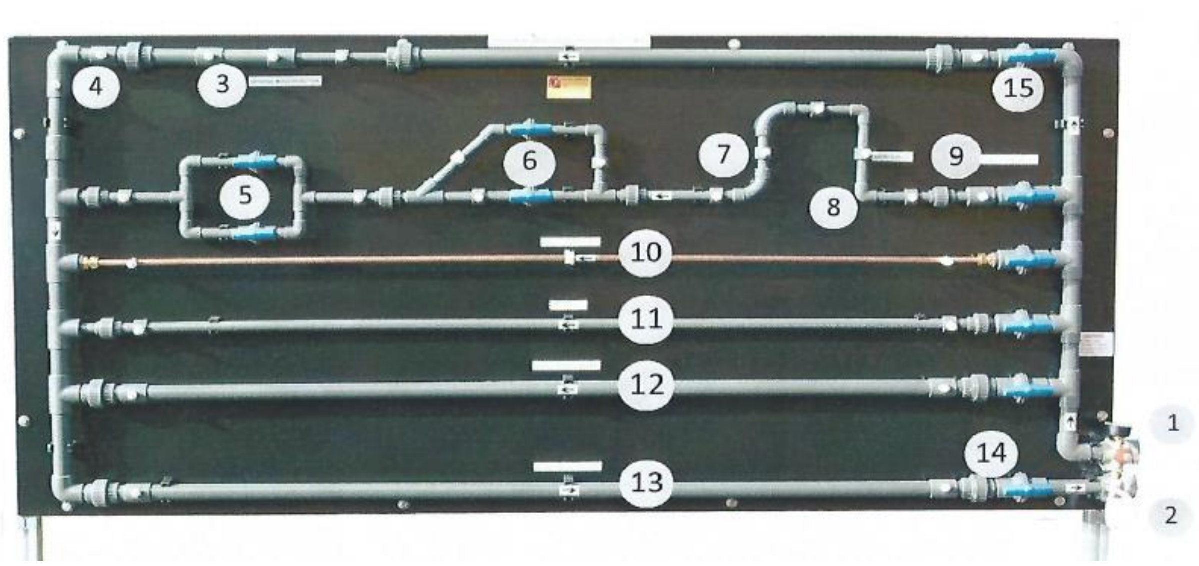
Tank should be filledapproximately half full with clean fresh water and tablets, which help the purification of water, must be placed in the **tank** (Add additional water if necessary to the **tank**if the drain extension tube is not submerged).

After turning on the HB100 by operating the **main power switch** on the front of the unit,**RCCB** should be testedfor correct operation and be sure that there are no leaks from the assembled pipe work.









Capabilities of Hydraulics Bench Experiment

1.Examination of Pressure Losses in Different Diameter Straight Length Pipes

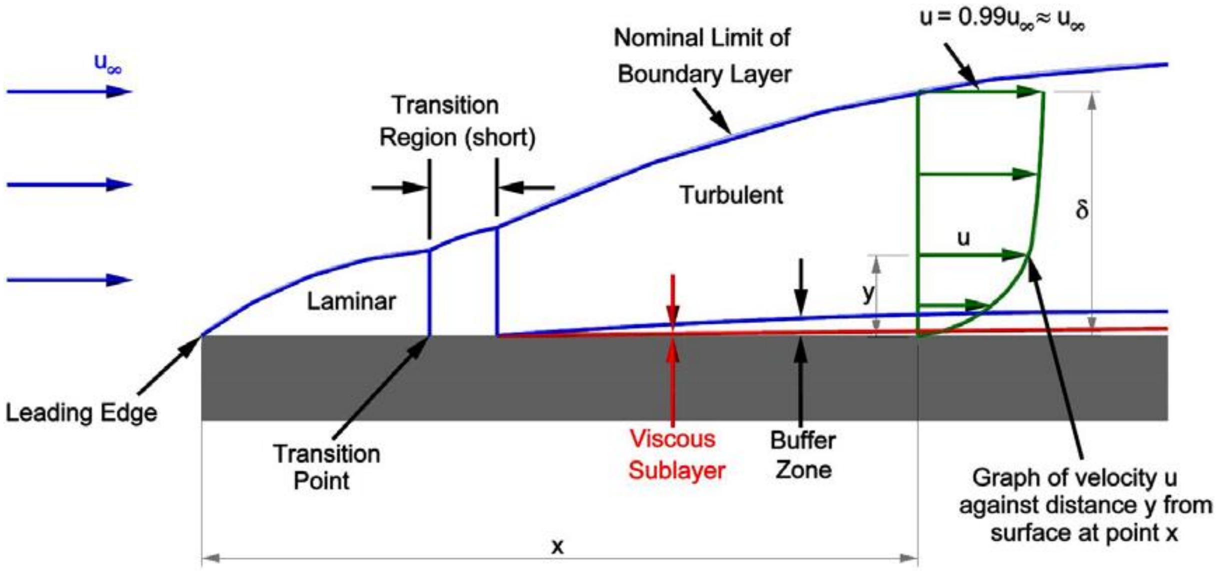
2.Demonstration of the Pressure Drop across a Sudden Constriction

3.Demonstration of Pressure Drop in Short and Long Elbows

Theory

The Hilton HB100D pressure losses in Pipes, bends and fittings module has been specificallydesigned to allow the study of different pipe fitting arrangements and there effects on pressureloss. As well as this there are different diameter and material pipes to allow study of boundary layerand friction factors that exist within the pipe.

When a fluid flows over a surface there is no slip at the interface betweenthe fluid and the surface. The velocity of the stream varies from zero at the surface to the velocityin the free stream U. This area of varying velocity is called the boundary layer.



The Figure represents flow over a flat smooth plate where the free stream velocity U isconstant over the complete length of the plate. The thickness of the boundary layer increasesfromthe leading edge as shown above. The flow in the boundary layer is laminar as indicated, but atsome point the flow makes a transition to turbulent flow. This transition is caused by randomturbulences in the boundary layer that grow with distance X along the plate until fully randomturbulent flow is seen. The non-dimensional number that can describe the position of thetransition, is the Reynolds number based upon the distant X. from the leading-edge.

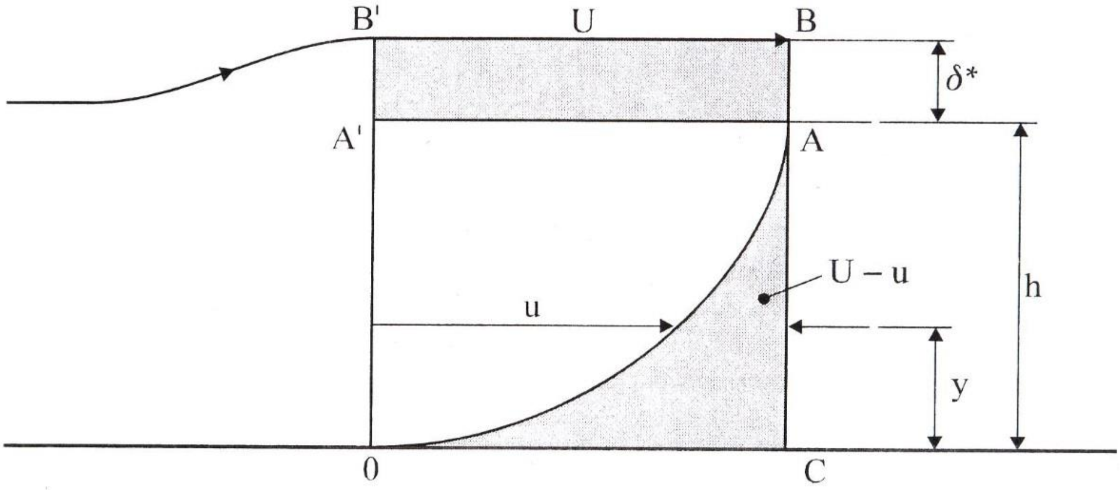
$$Re_x = \frac{Ux}{\upsilon}$$

Where; U is the free stream Velocity; x is the distance along the plate; υis the kinematic viscosity of the stream;

There is no one single value of Reynolds number to describe the exact location of the transitionpoint. This can be affected by stream turbulence and the surface roughness of the plate. Typicalvalues are found in the range 1 x 10^5 to 5 x 10^5.

Boundary layer Thickness

As the velocity approaching the edge of the boundary layer changes very slowly, it is difficult bydirect measurement to exactly locate the edge of the boundary layer.



It is useful to consider that the fluid outside the boundary layer is displaced away from theboundary by an additional layer shown above as δ*.

In the Figure 5, the curve 0A shows the distribution of velocity within the layer as a function ofdistance y from the surface. If there were no boundary layer the stream velocity U would exist,right down to the surface as shown by the line CA. The reduction in volume flow due to the reduction of velocity in the layer, is therefore

$$\Delta Q = \int_0^h (U-u)dy \qquad (1)$$

this corresponds to the shaded area 0AC in the diagram.

Definition of h

The dimension **h** is chosen so that **u=U** (the free stream velocity and hence the edge of theboundary layer) for any value of **y** greater than **h**.

If the total volume flow rate is considered to be restored five displacement of the streamlined atA'A way from the surface to a new position B'B through a distance δ*, the volume flow ratebetween A'A and B'B is also ΔQ. This is seen to be

$$\Delta Q = U\delta \qquad (2)$$

In simple terms the shaded areas are of equal area.

Equating (1) and (2) gives

$$\Delta Q = \int_0^h (U-u)dy = U\delta*$$

$$\delta* = \frac{1}{U}\int_0^h (U-u)dy$$

$$\delta* = \int_0^h (1-\frac{u}{U})dy$$

From the definition of h above it is an arbitrary height above the surface that describes the pointat which

u = U

Or

$\mathbf{1-\frac{u}{U}=0}$ for all values of y greater than h.

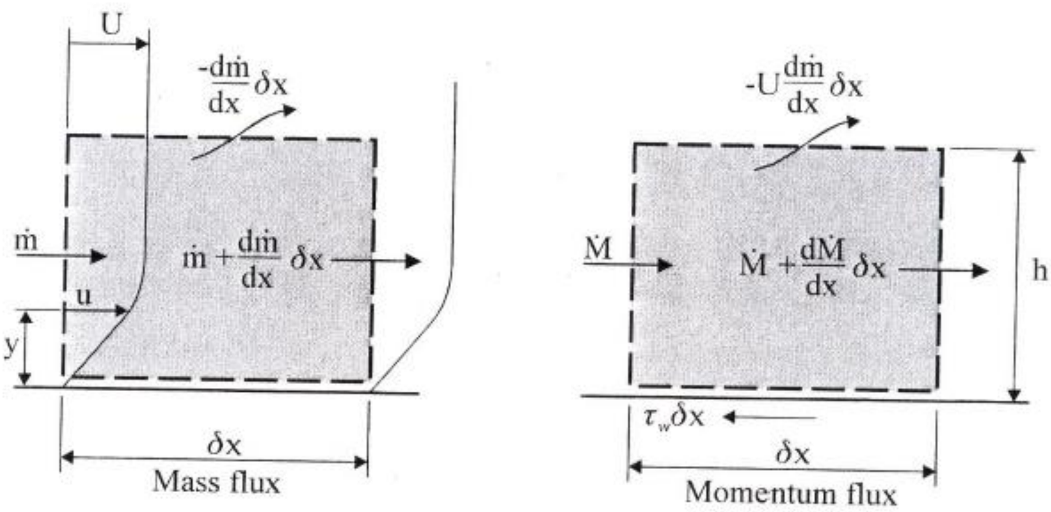
The value of h may be increased, indefinitely without affecting the value of the integral so we canallow h to increase towards infinity.

$h \to \infty$

Hence

$$\delta* = \int_0^\infty (1-\frac{u}{U})dy \qquad (3)$$

A further definition is necessary when momentum effects within the boundary layer are to beconsidered.



Looking at the Figure, there is a control volume of length δx and height h. Its depth is oneunit thickness, so that it represents a solid rectangle of depth one unit. The rate of mass flow intothe box is $\dot{\boldsymbol{m}}$. If the rate of outflow, at the right hand end is $\dot{\boldsymbol{m}} + \frac{d\dot{m}}{dx}\boldsymbol{\delta x}$ then for continuity to be maintained, the flow through the upper surface, must be $-\frac{d\dot{m}}{dx}\boldsymbol{\delta x}$ as shown Figure.

The momentum equation, may now be derived as follows.

Considering the right hand diagram, in the x direction the flow of momentum into and out of thebox is as follows.

$\dot{\boldsymbol{M}} + \frac{d\dot{M}}{dx}\boldsymbol{\delta x}$From the right hand end

$-\dot{\boldsymbol{M}}$ At the left hand end.

And $-\boldsymbol{U}\frac{d\dot{m}}{dx}\boldsymbol{\delta x}$at the upper surface. This is because over the upper surface the x component of velocity is U and from the diagram on the left the mass flow out is $-\frac{d\dot{m}}{dx}\boldsymbol{\delta x}$

The surface shear stress is τ_w acting in the direction shown in the diagram.

Equating the shear stress and change in momentum then gives.

$$\tau_w \delta x = \dot{M} + \frac{d\dot{M}}{dx}\delta x - \dot{M} - U\frac{d\dot{m}}{dx}\delta x$$

Or

$$\tau_w = U\frac{d\dot{m}}{dx} - \frac{d\dot{M}}{dx}$$

$$\tau_w = \frac{d}{dx}\left(U\dot{m} - \dot{M}\right) \qquad (4)$$

Per unit depth mass flow $\dot{\boldsymbol{m}}$

$$\dot{m} = \rho\int_0^h u\,dy$$

And momentum

$$\dot{M} = \rho\int_0^h u^2 dy$$

Substituting $\dot{\boldsymbol{m}}$and$\dot{\boldsymbol{M}}$ in equation (4) above.

$$\tau_w = \rho\frac{d}{dx}\left[\int_0^h \left(U\dot{m} - \dot{M}\right)dy\right]$$

$$= \rho U^2\frac{d}{dx}\left[\int_0^h \frac{u}{U}\left(1 - \frac{u}{U}\right)dy\right]$$

Since u=U for all values of y greater than h, the arbitrary upper limit may be replaced by ∞, this gives:

$$\tau_w = \rho U^2 \frac{d}{dx}\left[\int_0^\infty \frac{u}{U}\left(1-\frac{u}{U}\right)dy\right] \qquad (5)$$

It is convenient to expressτ_w, in a non-dimensional from as a local skin friction coefficient C_f.

$$C_f = \frac{\tau_w}{\frac{1}{2}\rho U^2} \qquad (6)$$

If the equation 5 is divided by *(1/2)*ρU^2 then it becomes

$$\tau_w = 2\frac{d}{dx}\left[\int_0^\infty \frac{u}{U}\left(1-\frac{u}{U}\right)dy\right] \qquad (7)$$

I we define new a new function

$$\Theta = \int_0^\infty \frac{u}{U}\left(1-\frac{u}{U}\right)dy \qquad (8)$$

Where Θis the momentum thickness of the boundary layer equation (7) becomes

$$D_f = 2\frac{d\Theta}{dx} \qquad (9)$$

The total skin friction force per unit width on a plate of length L is

$$D_f = \int_0^L \tau_w \, dx \qquad (10)$$

Writing $\tau_w$in terms of $C_f$from equation (6)

$$D_f = \frac{1}{2}\rho U^2 \int_0^L C_f \, dx$$

Substituting for $C_f$in the equation above

$$D_f = \frac{1}{2}\rho U^2 \times 2\int_0^L \frac{d\Theta}{dx}\, dx$$

When x = 0, Θ=0, and writing Θ_L for the momentum thickness at a distance L from the leadingedge,

$$D_f = \frac{1}{2}\rho U^2 \times 2\Theta_L \qquad (11)$$

The skin friction force $D_f$is now written in terms of a dimensionless overall skin frictioncoefficient$C_F$where

$$C_F = \frac{D_F}{1/2\rho U^2 L}$$

Substituting from equation (11) gives

$$C_F = \frac{2\Theta_L}{L} \qquad (12)$$

This equation gives the overall skin friction coefficient on a flat plate, very simply in terms of the momentum thickness at the trailing edge and the length of the plate L.

It is frequently useful to refer to the ratio of displacement thickness δ* to momentum thicknessΘ, and this is called the shape factor H., where,

$$H = \frac{\delta^*}{\Theta}$$

The results are shown for a laminar boundary layeralong a flat plate with a uniform free stream velocity. The results are shown in the following Table.

$y\sqrt{\mathrm{Re}_x}/x$	0	0.5	1.0	1.5	2.0	3.0	4.0	5.0	6.0
u/U	0	0.1659	0.3298	0.4868	0.6298	0.8461	0.9555	0.9916	0.9990

Note the dimensional as parameter $y\sqrt{Re_x}/x$used in the table, which generalizes the result toany value of distance x along the plate. For this laminar layer, the displacement thickness δ* andthe momentum thickness Θare given by,

$$\delta^* = \frac{1.721x}{\sqrt{\mathrm{Re}_x}} \qquad (14)$$

And

$$\Theta = \frac{0.664x}{\sqrt{\mathrm{Re}_x}} \qquad (15)$$

The shape factor H is

$$H = \frac{\delta *}{\Theta}$$

$$= \frac{1.721}{0.664}$$

$$=2.59$$

For a turbulent boundary layer along a smooth flat plate there are no corresponding calculatedresults frequently the velocity distribution is expressed in the following form.

$$\frac{u}{U} = \left(\frac{y}{\delta}\right)^{\frac{1}{n}} \qquad (16)$$

This is an empirical equation derived from experimental test series.

The index n varies from between 5 and 8 as the value of Re_x Increases in the range of 10^5 to 10^9.

There are many alternative expressions, similarly derived from test results.

The displacement and momentum sicknesses are frequently quoted as:

$$\delta * = \frac{0.046x}{Re_x^{0.2}} \qquad (17)$$

And

$$\Theta = \frac{0.036x}{Re_x^{0.2}} \qquad (18)$$

With shape factor H

$$H = \frac{\delta *}{\Theta}$$

Pressure Gradient Effects

The preceding analysis related to boundary layer development along the smooth plate with uniformflow in the free stream. Under these conditions, there zero pressure gradient effects, along theplate. If the stream however is accelerating or decelerating and large changes can take place in thedevelopment of the boundary layer. For accelerating free stream pressure falls in the direction offlow (following Bernoulli's equations) the pressure gradient being given by differentiating Bernoulli'sequations in the free stream.

$$\frac{dp}{dx} = -\rho U \frac{dU}{dx} \qquad (19)$$

The boundary layer grows less rapidly than in zero pressure gradient and transition to turbulence isinhibited. For a decelerating stream, the reverse effects are observed. The boundary layer growsmore rapidly in the shape factor increases in the downstream direction. The pressure rises in thedirection of flow, and this pressure rise tends to retard the fluid in the boundary layer, moreseverely than in the mainstream since it is moving slower.

Energy transfers from the free stream through the outer part of the boundary layer down towardsthe surface to maintain the forward movement against rising pressure. However, if the pressuregradient is sufficiently steep. This transfer will be insufficient to sustain the forward movement,and the flow along the surface will reverse resulting in separation of the mainstream from thesurface. This phenomenon is often seen in diffusers and on aerofoils at high angles of attack.

Experiment -3.1

Examination of Pressure Losses in Different Diameter Straight Length Pipes

<u>Aim of This Experiment.</u>

This experiment aimed to determine boundry layer thickness and energy loses causes friction on the pipes.

<u>Procedure</u>

1. Configure the pumps for parallelflow.
2. Switch on the pump(s).
3. Adjust the Flow to 50l/m using the flow control valve on the HB100.
4. Attach the positive end of the Manometer Coupling to the left hand side PressureTappingof the Smooth Pipe and the negative end to the right hand side. The flowof water in the Smooth Pipe is from left to right so the Manometer Coupling's arereversed for this pipe.
5. The pressure drop will be very small for the Smooth Pipe. In order to obtain a steadyreading place the Digital Manometer on a flat surface (such as a chair) in front of theHB100D and wait until the manometer tubes have stopped swinging.
6. Record the pressure drop.
7. Adjust the Flow rate to 40l/m and record the new pressure drop.
8. If only 1 pump is fitted the same procedure applies starting at a lower flow rate.
9. Reduce the flow rate until the lowest feasible flow rate is archived. It will be found that dueto the very small pressure drop in these pipes, operation at the lower end of the flow rangeis not practically feasible.
10. Once the Smooth Pipe is completed, switch the Manometer Coupling to theRough pipepressure tappings. The Rough Pipe operates from right to left. Ensurethe positive hose is connected to the right hand side tapping.
11. Repeat Steps 5 to 9.
12. Repeat the procedure again for the 20mm and ½" pipes.

Sample Test Results

32mm Smooth				
Flow Rate (L/m)	50	40	30	20
Pressure Drop (mbar)	13.4	8.9	4.6	2.3

32mm Rough				
Flow Rate (L/m)	50	40	30	20
Pressure Drop (mbar)	16.5	11.8	7.6	2.8

20mm				
Flow Rate (L/m)	50	40	30	20
Pressure Drop (mbar)	128.4	91.0	52.2	25.1

1/2"			
Flow Rate (L/m)	37.5	30	20
Pressure Drop (mbar)	515.0	357.0	177.8

Experiment -3.2

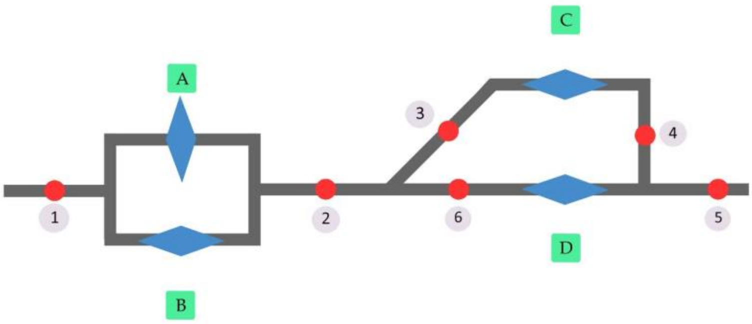
Demonstration of the Pressure Drop across a Sudden Constriction

Aim of This Experiment.

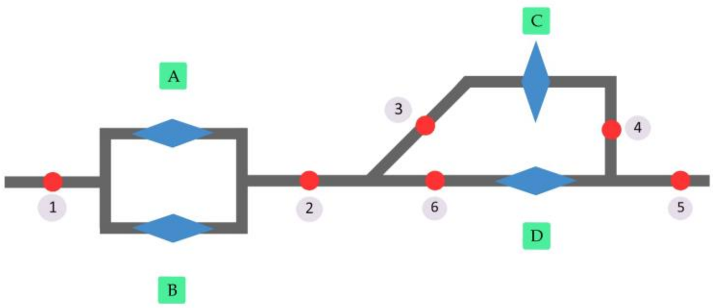
This experiment aimed to determine velocity changes and pressure drops on sudden constriction connection.

Procedure

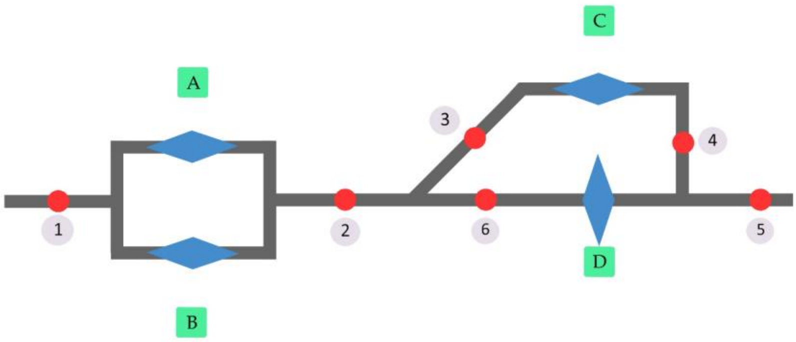
1. Configure the pumps for parallelflow.
2. Switch on the pump(s).
3. Adjust the Flow to 50l/m using the flow control valve on the HB100.
4. Attach the positive end of the Manometer Coupling to the right hand side PressureTapping of the Sudden Constriction and the negative end to the left hand side. Theflow of water in this section is from right to left.
5. Record the flow rate and pressure drop.
6. Reduce the flow rate to 40l/m and repeat the observations.
7. Repeat this procedure until the lowest sensible results are achieved.
8. Close Valve A as shown below and repeat the test again.



9. Open Valve A and close Valve C as shown below and repeat the test again.



10. Open Valve C and close Valve D as shown below and repeat the test again.


C
A
3
4
1
2
6
5
D
B

Sample Test Results

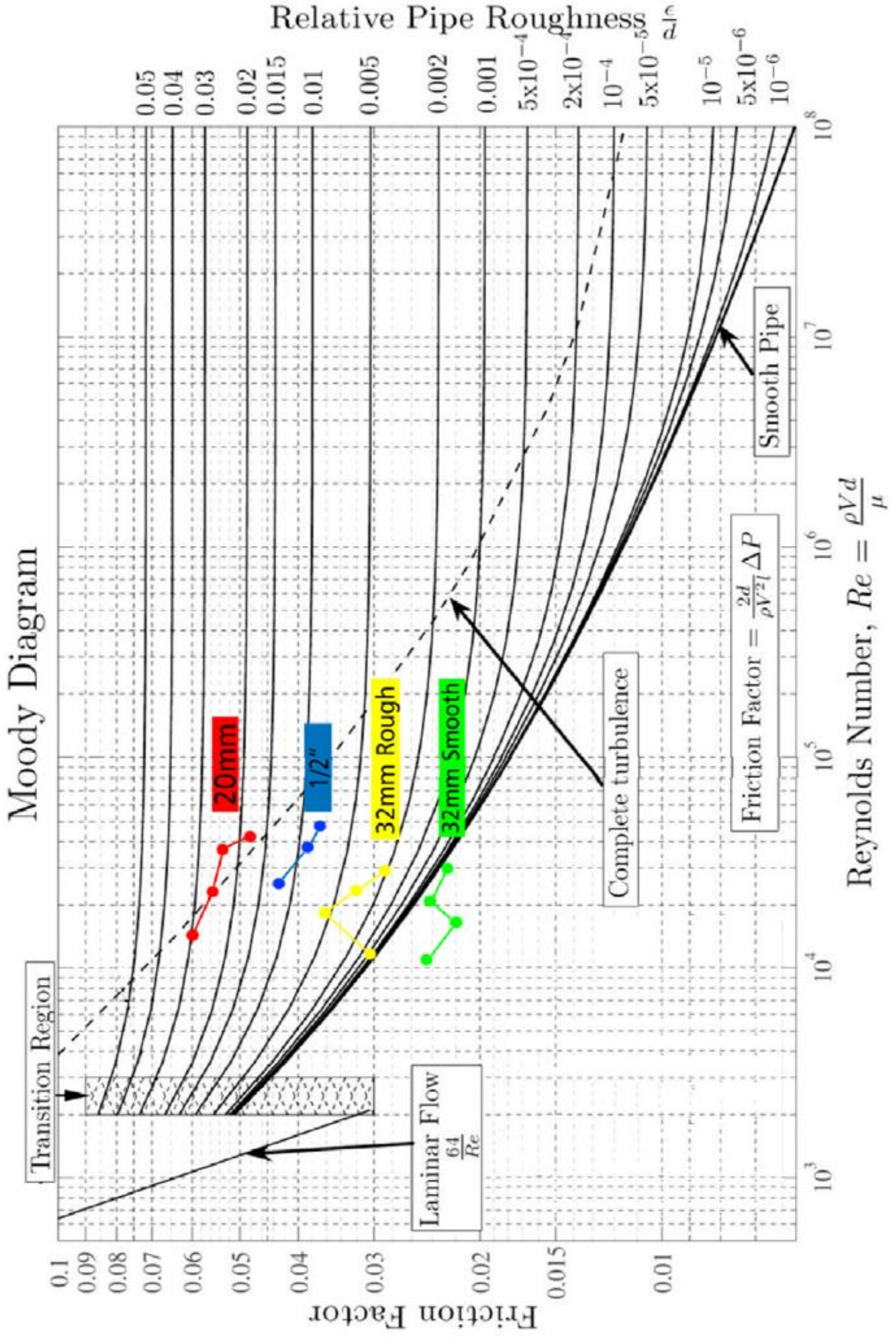
Sudden Constriction				
Pipe Diameter (m)	0.016	0.016	0.016	0.016
Area m2	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Flow Rate (L/m)	46	36	28	19
Flow Rate (m3/s)	7.65E-04	5.99E-04	4.66E-04	3.16E-04
Velocity	3.81E+00	2.98E+00	2.32E+00	1.57E+00
Reynolds Number	46604	36473	28368	19250
Pressure Drop (mbar)	81.6	46.6	35.7	15.9
Pressure Drop (Pa)	8160	4660	3570	1590

Valve A Closed Sudden - Constriction				
Pipe Diameter (m)	0.016	0.016	0.016	0.016
Area m2	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Flow Rate (L/m)	45	35	27.5	19
Flow Rate (m3/s)	7.49E-04	5.82E-04	4.58E-04	3.16E-04
Velocity	3.72E+00	2.90E+00	2.28E+00	1.57E+00
Reynolds Number	45591	35460	27861	19250
Pressure Drop (mbar)	77.6	44.7	33.9	16.7
Pressure Drop (Pa)	7760	4470	3390	1670

Valve C Closed Sudden - Constriction				
Pipe Diameter (m)	0.016	0.016	0.016	0.016
Area m2	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Flow Rate (L/m)	46	36	28	19
Flow Rate (m3/s)	7.65E-04	5.99E-04	4.66E-04	3.16E-04
Velocity	3.81E+00	2.98E+00	2.32E+00	1.57E+00
Reynolds Number	46604	36473	28368	19250
Pressure Drop (mbar)	78.6	45.8	34.2	16.6
Pressure Drop (Pa)	7860	4580	3420	1660

Valve D Closed - Sudden Constriction				
Pipe Diameter (m)	0.016	0.016	0.016	0.016
Area m2	2.01E-04	2.01E-04	2.01E-04	2.01E-04
Flow Rate (L/m)	45	35.5	27.5	19
Flow Rate (m3/s)	7.49E-04	5.91E-04	4.58E-04	3.16E-04
Velocity	3.72E+00	2.94E+00	2.28E+00	1.57E+00
Reynolds Number	45591	35966	27861	19250
Pressure Drop (mbar)	76.6	40.7	33.2	15.1
Pressure Drop (Pa)	7660	4070	3320	1510

Appendix – I Some Useful Data



Kinematic viscosity, ν, of water at varying temperatures:

Temperature (°C)	Kinematic Viscosity (m²/s) x 10⁻⁶
0	1.787
5	1.519
10	1.307
20	1.004
30	0.801
40	0.658
50	0.553
60	0.475
70	0.413
80	0.365
90	0.326
100	0.29