EXPERIMENTAL AERODYNAMICS

FLOW TROUGH AN ORIFICE

LAB SHEET

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1- Introduction

When a fluid passes through a constriction, such as through a sharp-edged hole or over a weir, the constriction contracts the fluid stream, so it is not uniform and parallel. This contraction can continue some distance downstream of the constriction. The contraction reduces the overall flow, which means that you must understand and allow for it in any calculations you make for flow through the nozzle or orifice.

The TecQuipment Flow Through an Orifice (H4) fits onto either of TecQuipment's Hydraulic Benches. It allows students to experiment with flow, coefficients and contraction of a vertical jet of water passing through a sharp-edged circular orifice. TecQuipment also offer two different sets of optional nozzles and orifices for use this equipment.

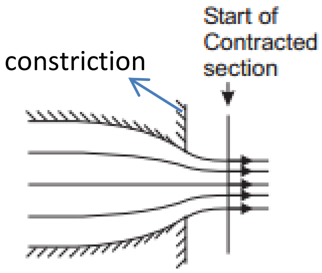
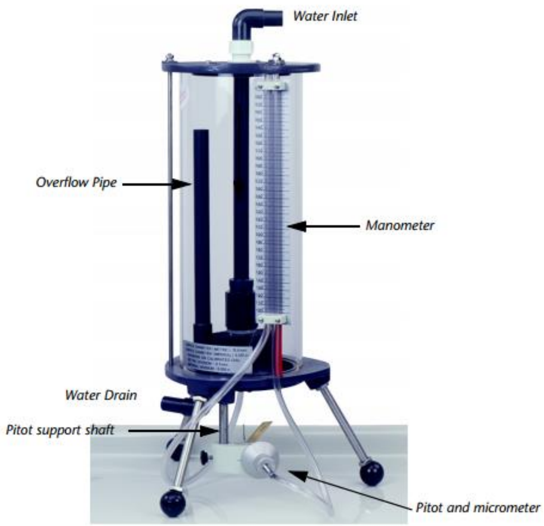


Figure 1.Constriction and Contracted Section

2- Main Parts



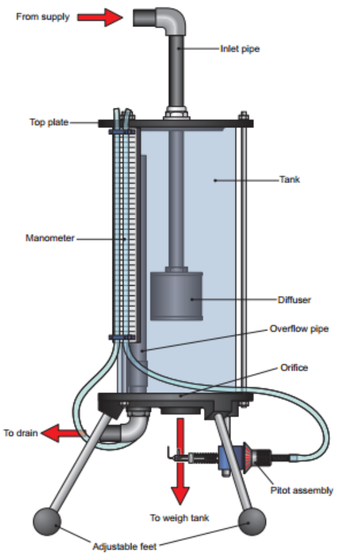


Figure 2. Main Parts of equipment   Figure 3. Detailed Drawing of the Apparatus

Figure 2 shows the main parts of the equipment - shown on the top of a TecQuipment Hydraulic Bench (supplied separately). Figure 3 shows a more detailed drawing of the apparatus.

The main part is a transparent cylindrical tank held between a top and bottom plate by three threaded bars. The whole assembly sits on three adjustable legs. The tank has a water inlet to the top, an overflow pipe that exits through the bottom of the tank and an outlet hole in the middle of the bottom plate.The orifices (one supplied as standard) fit into the hole in the bottom of the tank.

The water enters the top of the tank through a vertical inlet pipe. The bottom of the inlet pipe has a water settler which sits below the normal water level and helps stabilize the flow as it enters the tank. The inlet pipe has an adjustable fitting so the user may adjust the height of the inlet pipe for different experiments. An overflow pipe directs the surplus water back to drain. This helps keep a constant level or ‘Head’ of water in the tank for some experiments. The water also passes out through the orifice fitted in the hole in the bottom of the tank. The emerging ‘jet’ passes over a Pitot tube assembly, then back to the hydraulic bench for flow measurement.

Two clear plastic tubes mount in front of a vertical scale, forming two manometers. The manometer scale clips to one of the three bars that hold the top and bottom plate to the tank. One manometer tube connects to a pressure tapping in the base of the tank to show the water level in the tank with respect to the bottom of the tank. The other tube connects to the Pitot assembly to show the total jet head (pressure in millimetres of water) measured at the Pitot tip.

The Pitot assembly includes a micrometer-style adjustmentfor precise control of Pitot position. A 3 mm thick angled pointer allows you to accurately measure the width of the jet using the micrometer.

3- Theory

Flow Through Orifices and Nozzles – Background

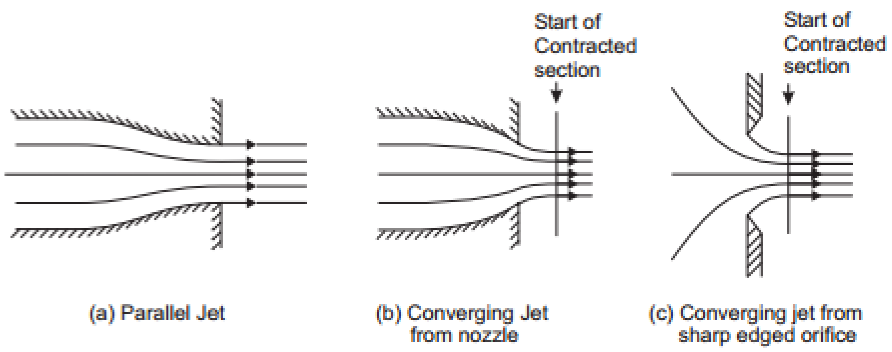


Figure 4. Flow from Nozzles and an Orifice

Drawing (a) shows fluid streaming through a smoothly contracting nozzle, making a parallel jet. The overall increase in speed through the contraction reduces non-uniformity in the approaching flow, so the fluid velocity should be uniform across the emerging jet. The cross-sectional area of the jet is the same as that of the nozzle, so the flow rate is the product of the jet velocity and the nozzle area.

In drawings (b) and (c) however, the fluid does not emerge as a convergentstream, so the crosssectional area of the jet reduces to a contracted section or ‘vena contracta’. Over this section the streamlines are parallel and velocity is effectively uniform. The flow rate is the product of the jet velocity and area of the contracted section.

Flow Theory

Figure 5 shows a theoretical cross-section of the tank, showing the main features of flow through the orifice. The tank is large enough to assume there is no fluid flow except for that part near to the orifice. In this part, the fluid accelerates towards the centre of the orifice, and the curvature of the streamlines (shown as MN) reduces the jet diameter and therefore area.

The reduction in area due to the curvature extends to (or the vena contracta starts at) a downstream position at a distance of between half the orifice diameter (D/2) and a complete diameter (D).

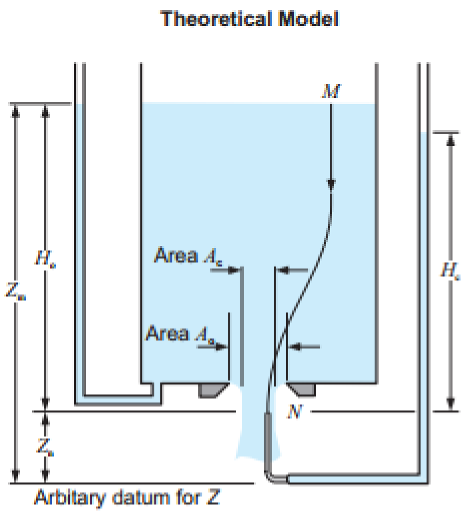


Figure 5. Theoretical Cross-section Showing Main Features

Consider now the total head of the water at points M and N of a typical streamline, M being in the surface and N being in the plane of the vena contracta. From Bernoulli, with reference to a datum, the total head at M is:

$$\frac{{u_m}^2}{2g} + P_m + z_m$$

and at N is:

$$\frac{{u_n}^2}{2g} + P_n + z_n$$

so that, if the energy were conserved, i.e. if there were no loss of total head:

$$\frac{{u_m}^2}{2g} + P_m + z_m = \frac{{u_n}^2}{2g} + P_n + z_n \qquad (1)$$

As mentioned earlier, Pm and Pn are equal (both at atmospheric pressure) and umis negligibly small according to our assumption. Also, from the diagram, you can see that,

$$z_m - z_n = H_o \qquad (2)$$

so that, from Equations (1) and (2), the ideal velocity at Nis given by:

$$\frac{{u_n}^2}{2g} = H_o \qquad (3)$$

This result applies to all points in the plane of the vena contracta, so changing the notation to let u0 be the ideal velocity in the plane of the vena contracta, which would occur if there was no energy loss.

$$\frac{{u_o}^2}{2g} = H_o \qquad (4)$$

Because of the energy loss, which in fact takes place as the water passes down the tank and through the orifice, the actual velocity uc in the plane of the vena contracta is less than uo , and may be calculated from the Pitot tube using equation 5:

$$\frac{{u_c}^2}{2g} = H_c \qquad (5)$$

From these equations:

$$Energy\ loss: H_o - H_c$$

<u>Coefficients:</u>

The coefficient of velocity(C_u) is the ratio of actual velocity uc and ideal velocity uo through the orifice. From Equations (4) and (5), we obtain:

$$C_u = \frac{u_c}{u_o} = \sqrt{\frac{H_c}{H_o}} \qquad (6)$$

In a similar sense, the coefficient of contraction C_c is defined as the ratio of the cross-section of the vena contracta A_c, to the cross-section of the orifice A_o,

$$C_c = \frac{A_c}{A_o} \qquad (7)$$

The orifice area A_c applies to a circular orifice (πr^2).

Finally, the coefficient of discharge C_d is the ratio of the actual discharge to that which would take place if the jet discharged at the ideal velocity without any reduction of area. The actual discharge Qis given by:

$$Q = u_c A_c \qquad (8)$$

and if the jet discharged at the ideal velocity u_0 over the orifice area a_0, the discharge Q_0 would be:

$$Q_o = u_o A_o = A_o \sqrt{2gH_o} \qquad (9)$$

So, from the definition of the coefficient of discharge,

$$C_d = \frac{Q}{Q_o} = \frac{u_c A_c}{u_0 A_0} \qquad (10)$$

Or C_d can be expressed

$$C_d = C_u * C_c \qquad (11)$$

Typical Coefficient Values

Figure shows the typical values of C_d for two different orifices. In general, the smoother the entrance to the orifice or nozzle, the higher the value for coefficient of discharge.

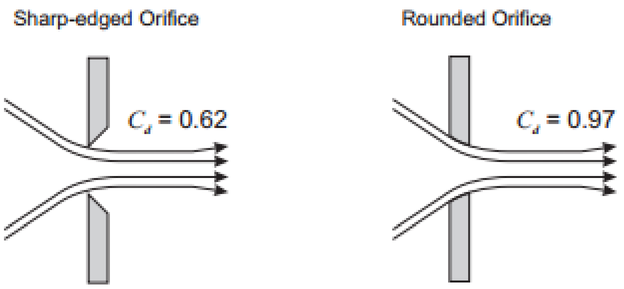


Table gives typical values of coefficients for a sharp-edged circular orifice.

C_u	C_c	C_d
0.97 to 0.99	0.61 to 0.66	0.6 to 0.65

In experiment sharp-edged circular orifice will be used. You will compare tables values with your calculations.

4- Aim

To calculate coefficient values for different volumetric flow rates, compare this values with table values and examine C_d-Flow rate distrubition in a graph.

5- Procedure

1. Set up the tank on the hydraulic bench as described in Installation guide.

2. Start the pump of the hydraulic bench and adjust the flow so the level in the tank stays just above the overflow pipe in the tank.

3. Adjust the vertical inlet pipe upwards so that its outlet is just below the surface of the water in the tank.

4. Allow conditions to stabilize and use the hydraulic bench to measure the flow(flow rate). Record the head pressures (H_o and H_c)

5. Reduce the inlet flow (supply from the hydraulic bench) and again measure the flow.

6- Calculations

	1	**2**	**3**	**4**	**5**	**6**
Orifice:	**Sharp-Edge**					
Orifice Diameter D (m)	0,013	0,013	0,013	0,013	0,013	0,013
Orifice Area A_o (m^2)						
Water Collected (Liter)						
Time (seconds)						
Flow Rate Q (m^3/s)						
Head H_o (m)						
Pitot Reading H_c (m)						
Jet Diameter D (m)						
C_u						
C_c						
C_u*C_c =C_d						

Calculate C_u, C_c and C_d values for 6 flow rate.

Compare this values table values which are shown above.

Show discharge coeff.(C_d) - Flow Rate distrubition on a graph like given below.

Standard 13 mm Round Orifice (Sharp-edged)