Experiment A
Orifice and Free Jet Flow

Reading: Douglas Fluid Mechanics 6.13

1. Objectives

The objective of this experiment is to determine the coefficient of velocity of two small orifices, by measurement of the trajectory of a jet issuing from an orifice in the side of a reservoir under steady flow conditions (constant reservoir head).

2. Experimental Procedure and Measurements

Remove the orifice plate by releasing the two knurled nuts and check the orifice diameter; take care not to lose the O-ring seal. Replace the orifice and connect the reservoir inflow tube to the bench flow connector. Position the overflow connecting tube so that it will discharge into the volumetric tank; make sure that this tube will not interfere with the trajectory of the jet flowing from the orifice.

Turn on the pump and open the bench valve gradually. As the water level rises in the reservoir towards the top of the overflow tube, adjust the bench valve to give a water level of 2–3 mm above the overflow level. This will ensure a constant head and produce a steady flow through the orifice.

2.1. Experiment 1

- **Determination of Coefficient of Velocity from Jet Trajectory.**

Position the overflow tube to give a high head. Note the value of the head. The jet trajectory is obtained by using the needles mounted on the vertical backboard to follow the profile of the jet. Release the securing screw for each needle in turn and move the needle until its point is just immediately above the jet: then re-tighten the screw. Attach a sheet of paper to the back-board between the needle and board and secure it in place with the clamp provided so that its upper edge is horizontal. Mark the location of the top of each needle on the paper. Note the horizontal distance from the plane of the orifice (taken as $x = 0$) to the coordinate point marking the position of the first needle.

This first coordinate point should be close enough to the orifice to treat it as having the value $y = 0$. Thus y displacements are measured relative to this position. Estimate the likely experimental errors in each of the quantities measured.

Repeat the test for a low reservoir head.

Then repeat the procedure for the second orifice. Plot x vs. $\sqrt{yh}$ and determine the slope of the graph. The velocity coefficient C_v is equal to the average slope /2.

2.2. Experiment 2

- **Determination of Coefficient of Discharge under Constant Head.**

Measure the flow rate by timed collection, using the measuring cylinder provided, and note the reservoir head value. Repeat this procedure for different heads by adjusting the level of the overflow tube. Plot flowrate Q_t vs. $\sqrt{h}$ and determine the slope of the graph. The coefficient of discharge C_d can then be calculated from

$$Cd = \frac{slope}{A_0\sqrt{2g}}$$

2.3. Technical Data

Diameter of small orifice	3 mm
Diameter of large orifice	6 mm
Surface area of reservoir	$A_R = 1.812 \times 10^{-3}$ m^2

3. Theory

3.1. Experiment 1

From the application of Bernoulli's Equation, the ideal orifice outflow velocity at the jet vena contracta (narrowest diameter of the jet) is

$$v_i = \sqrt{2gh}$$

where h is the height of fluid above the orifice. The actual velocity is

$$v = C_v\sqrt{2gh}$$

C_v is the coefficient of velocity, which allows for the effects of viscosity, and so $C_v < 1$. C_v can be determined from the trajectory of the jet using the following argument:

Neglecting the effect of air resistance, the horizontal component of the jet velocity can be assumed to remain constant so that in time t, the horizontal distance travelled,

$$x = vt$$

Because of the action of gravity, the fluid also acquires a downward vertical (y-direction) component of velocity. Hence, after the same time t, the jet will have a y-displacement

$$y = \frac{1}{2}gt^2$$

$$t = \sqrt{\frac{2y}{g}}$$

Substitution for t from (3) into (2), and for v from (1) into (2) yields the result:

$$C_v = \frac{x}{2}\frac{1}{\sqrt{yh}}$$

Hence, for steady flow conditions, i.e. constant h, C_v can be determined from the x, y coordinates of the jet. A graph of x plotted against $\sqrt{yh}$ will have a slope of 2 C_v.

3.2. Experiment 2

The actual flow rate of the jet is given by

$$Q_t = A_c v$$

where A_c is the cross-sectional area of the vena contracta, given by

$$A_c = C_c A_0$$

where A_0 is the orifice area and C_c is the coefficient of contraction, and therefore $C_c < 1$.

Hence

$$Q_t = C_c A_0 C_v \sqrt{2gh}$$

The product $C_c C_v$ is called the discharge coefficient, C_d, so finally

$$Q_t = C_d A_0 \sqrt{2gh}$$

If C_d is assumed to be constant, then a graph of Q_t plotted against $\sqrt{h}$ will be linear and the slope, $S = C_d A_0 \sqrt{2g}$.

3.3. Vena Contracta

An orifice is an opening, usually circular, in the side of a tank through which fluid is discharged in the form of a jet, usually into the atmosphere. The volume rate of flow through the orifice will depend on the head of fluid above the level of the orifice. It is assumed that the orifice is small, i.e. that the head does not vary across the orifice itself.

One important aspect of the flow through the orifice is that the streamlines at the orifice itself are not parallel. Upstream of the orifice, water will flow towards the orifice from a wide area around it, and the streamlines are therefore curved in towards the orifice (see figure 1). This curvature continues as the jet emerges from the orifice, with the result that by the time the jet has developed fully and the streamlines are parallel, the actual diameter of the jet is considerably smaller than the diameter of the orifice from which it has emerged. The section through the jet at which the streamlines are parallel (i.e. where the jet starts to be of constant cross-section) is known as the *Vena Contracta*.

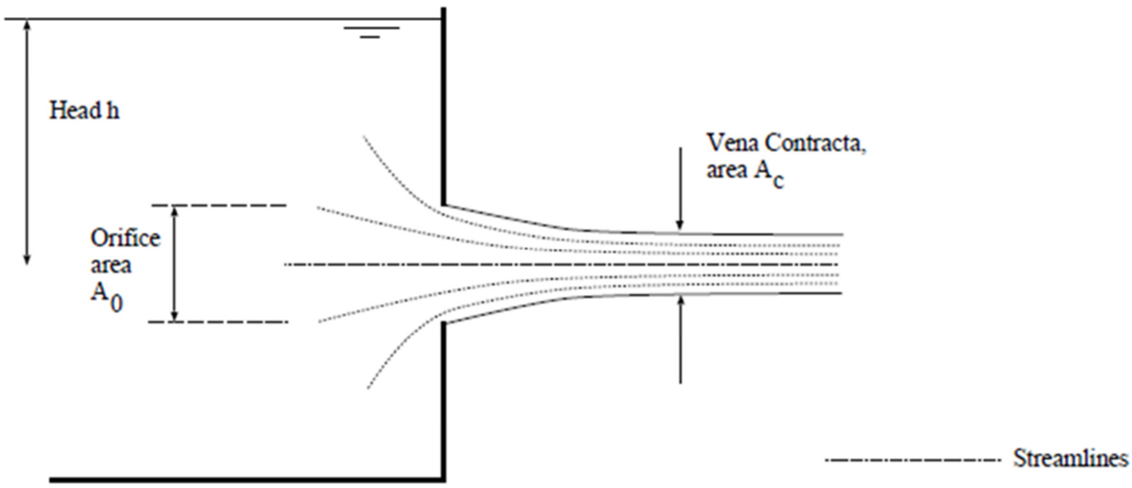

Figure 1: Jet emerging from an orifice, showing the streamlines and Vena Contracta

4. Individual report

Each studentmust submit ONE experimental report (with all BART sheets attached at the front). The report has to be NO MORE THAN 5 PAGES LONG (1.5 line space, font size 11) and it must include: student names, title, theory, method, results, analysis, and conclusions. Use appropriate graphs, charts, tables, regression analysis, and error analysis as required. Use references where needed. References do not count towards the page limit.