**Aim**

To determine experimentally the hydraulic coefficients of a small orifice and compare the coefficient of discharge with that of obtained from empirical data.

**Introduction**

In Fig. 1, a reservoir fitted with a sharp edged opening of small dimensions, known as a small orifice, is shown. The reservoir contains a liquid with its free surface at a height of “H” m above the center of the orifice. The fluids flowing out of the orifice is discharged into the atmosphere.

The pattern of stream lines in the vicinity of the orifice is shown in Fig. 2. As can be seen from this figure, all the fluid particles, except those on the axis of the orifice will have to change their direction of motion on approaching the orifice. This change in direction of motion results in centrifugal forces directed towards the axis of the orifice. Due to these lateral inertial forces, the jet issuing out of the orifice will be subjected to a contraction till the fluid particles start moving along straight and parallel paths. The section at which the paths of the fluid particles first become parallel is known as the “Vena-Contracta”.

Beyond the vena-contracta, if the aeration of the jet and the frictional losses acting at the boundary are negligible, the jet velocity will increase due to the action of gravity. This increase of velocity will reduce with the cross sectional size of the jet (It may be mentioned that quite often the definition of the vena-contracta is given as the section of the jet where the cross-
sectional area is minimum. This is an erroneous definition). However this contraction beyond vena-contracta is very gradual and its nature is altogether different from that of the contraction the jet experiences prior to vena-contracta and such as Bernoulli’s equation can be applied at the vena-contracta and sections downstream of it. Since the stream lines are curved, the Bernoulli’s theorem cannot be applied for sections between the orifice opening and the vena-contracta.

If the orifice is circular and diameter “d”, then according to the available experimental data, vena-contracta occurs from the plane of the orifice, at a distance of,

\[ l_0 = 0.5d \]

-------(1)

If the vertical dimension of the vena-contracta is less than 0.1H, the orifice is known as a small orifice and in such a case, the variation of the velocity along the vertical dimension of the vena-contracta can be neglected.

**Specifications**

1. Diameter of the orifice, \( d = \)
2. Area of the orifice, \( a = \frac{\pi d^2}{4} = \)
3. Coordinates of the center of the vena-contracta:
   - Horizontal, \( x_1 = \)
   - Vertical, \( y_1 = \)
4. Zero error of the gauge glass scale, \( \Delta H = \)
5. Size of the measuring tank =

**Experimental Set-up**

The experimental setup is schematically shown in Fig. 3. It consists of a tall reservoir on a suitable stand known as the orifice tank. On one vertical side of the tank, a sharp edged orifice is provided and vertically above it, a scale is fixed horizontally so that the jet issuing out of the orifice and the scale are in one plane. Along the horizontal scale moves a slide which is provided with a vernier.

A vertical scale carrying a pointer at its lower end moves within the slide and a vernier is provided on the slide for the vertical scale also. Thumbscrews are provided to fix the slide on the horizontal scale and the vertical scale on the slide. With the help of these two scales the horizontal and vertical coordinates, \( x \) and \( y \) of the center of the jet at any cross-section as referred to the center of the vena-contracta can be determined.
The orifice tank is provided with a vertical gauge glass fitted over a scale with the help of which the height of the free surface of water above the center of the vena-contracta can be determined.

A pipe leads water from the mains into the orifice tank and the rate of supply can be adjusted with the help of a valve provided on the supply pipe. The orifice tank is provided with an overflow and a drain.

The water issuing out of the orifice gets collected in a measuring tank. The measuring tank is partitioned into two parts. The water admitted into the smaller part is directly led into the drain whereas the water admitted into the bigger part can be collected. The bigger part of the measuring tank is provided with a gauge glass fitted vertically against a vertical scale with the help of which the volume of water collected in a given time can be measured. This half of the measuring tank is also provided with a drain pipe and a valve so that it can be emptied whenever necessary. A hopper arrangement is provided which can be used to lead the incoming water into either part of the measuring tank.

![Experimental Setup Diagram]
Assuring that all the fluid particles of the jet at the orifice opening moving along parallel paths in a direction normal to the plane of the orifice with a velocity head equal to the height of the water surface in the orifice rank above the center of the orifice, the equation for the theoretical discharge through the orifice can be derived in the form,

\[ Q_{th} = a \sqrt{2gH} \]  \hspace{1cm} (2)

Where,
- \( Q_{th} \) = Theoretical rate of discharge through the orifice in m³/s.
- \( a \) = Area of the orifice in m².
- \( H \) = Height of water level in the orifice tank above the center of the orifice in m.
- \( g \) = Acceleration due to gravity in m/s².

As explained earlier, the paths of fluid particles become parallel only at the vena-contracta and the Bernoulli’s Theorem cannot be applied at sections of the jet on the upstream side of the vena-contracta. However, at vena-contracta, the cross-sectional area of the jet “\( a_c \)” will be less than “\( a \)”, the area of the orifice because of the contraction. Hence,

\[ C_c = \frac{a_c}{a} < 1 \]  \hspace{1cm} (3)

This ratio “\( C_c \)” is known as the coefficient of contraction. Further, the flow of any real fluid is accompanied by energy dissipation and hence the actual velocity at the vena-contracta “\( V_c \)” can be expressed as:

\[ V_c = C_v \sqrt{2gH} \]  \hspace{1cm} (4)

Where \( C_v \), is known as the “coefficient of velocity” and accounts for all types of losses that occur in the flow till the fluid particles reaches vena contracta. Hence, the actual discharge through the orifice can be expressed as

\[ Q = a_c * V_c = C_c * C_v * a \sqrt{2gH} = C_d * a \sqrt{2gH} \]  \hspace{1cm} (5)

Where,
- \( Q \) = Actual discharge past the orifice and
- \( C_d = C_c * C_v \)  \hspace{1cm} (6)

Here, \( C_d \) is known as the “coefficient of discharge”. Beyond the vena-contracta the jet falls down under the action of gravity and the geometry of the jet can be considered to be a parabola as in the case of horizontally ejected projectile. If \( x \) and \( y \) are the horizontal and vertical coordinates of the center of the jet at an arbitrarily chosen section referred to the center of the vena-contracta, the coefficient of velocity is given by the equation,

\[ C_v = \frac{x}{\sqrt{4yH}} \]  \hspace{1cm} (7)

The rate of discharge “\( Q \)” can be experimentally determined by noting the volume “\( V \)” m³ of water that is collected in the measuring tank during a time “\( t \)” s. Then,
\[ Q = \frac{V}{t} \] ------ (8)

The coefficient of discharge can now be determined as,
\[ C_d = \frac{Q}{a\sqrt{\frac{gH}{2}}} \] ------ (9)

The coefficient of contraction can be computed as,
\[ C_c = \frac{C_d}{C_v} \] ------ (10)

The empirical equation in use for computation of the coefficient of discharge of circular orifices is,
\[ C'_d = 0.6075 + 0.0098 \sqrt{\frac{H}{0.305}} - 0.0133d \] ------ (11)

**Experimental procedure**

1. Fit the required circular orifice to the orifice tank and note down its diameter.
2. Admit a little water into the orifice tank and with the drain, adjust the water level in the tank to coincide with lowest point of the orifice. The water level in the gauge glass should be below the zero of the scale at a distance equal to the radius of the orifice. If not, determine the zero error of the gauge glass scale of the orifice tank.
3. Open out the valve on the supply line and adjust the head causing the flow that it has the maximum possible value.
4. Adjust the pointer so that its tip is at the center of the vena-contracta and note down the readings on the horizontal and vertical scales.
5. After allowing some time for the flow to settle down, note down the reading of the gauge glass scale of the orifice tank.
6. Move the pointer so that its tip coincides with the center of the jet cross-section sufficiently away from the vena-contracta and note down the readings of the horizontal and vertical scales.
7. Note down the rise in water level in the measuring tank for a specified time.
8. With the valve on the supply pipe, regulate the head causing flow in uniformly distributed steps and for each step, repeat the procedure given in 5, 6 and 7.

**Sample Calculation**
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<th>Sl. No.</th>
<th>log Q</th>
<th>log H</th>
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\[ Q' = \frac{C_d' \cdot a \cdot \sqrt{2g}}{\sqrt{H}} \]

\[ C_c = \frac{C_d}{C_v} \]
\[ C_v = \frac{x}{\sqrt{yH}} \]
\[ y = (y_2 - y_1) \quad \text{cm} \]
\[ x = (x_2 - x_1) \quad \text{cm} \]

**Coefficient of Velocity**

**Coefficient of Discharge**
\[ C_d = 0.6075 + 0.0098 \sqrt{0.305H - 0.0133d} \]
\[ Q = \frac{a \cdot \sqrt{2g} \cdot \sqrt{H}}{C_d} \]

**Rate of Discharge**
- Rate of Discharge, \( Q \) (experimental) \(*10^4 \) m\(^3\)/s
- Time of collection, \( t \) s
- Volume collected, \( V = \left( \frac{l_2 - l_1}{100} \right) \cdot A \) m\(^3\)
- Rise in level, \( (l_2 - l_1) \) cm
- Final level in measuring tank, \( l_2 \) cm
- Initial level in measuring tank, \( l_1 \) cm

**Head**
- Head causing flow \( H = H_i \pm \Delta H \) cm
- Head indicated by the scale of orifice tank \( H_i \) cm
Graphs

- $C_d, C_c, C_v, C_d' \text{ vs } H$
- $Q \text{ vs } H$
- $\ln Q \text{ vs } \ln H$

Result

Inference