Chemical Engineering Laboratory

Table of Contents

1. Orifice and Jet Flow Experiment 2
   1.1. Using the Bernoulli Equation 2
   1.2. Using the Kinematic Equations 2
   1.3. Using the X and Y values of the Needles to find the Actual Velocity 3
   1.4. Coefficient of Velocity 3
   1.5. Coefficient of Discharge 4
   1.6. Experiment Procedures according to the manuscript 5
   1.7. Blank Data Sheet 6

1. Orifice and Jet Flow Experiment

The goal of this experiment is to determine the coefficient of velocity C_v and the coefficient of discharge C_d of water leaving an orifice.

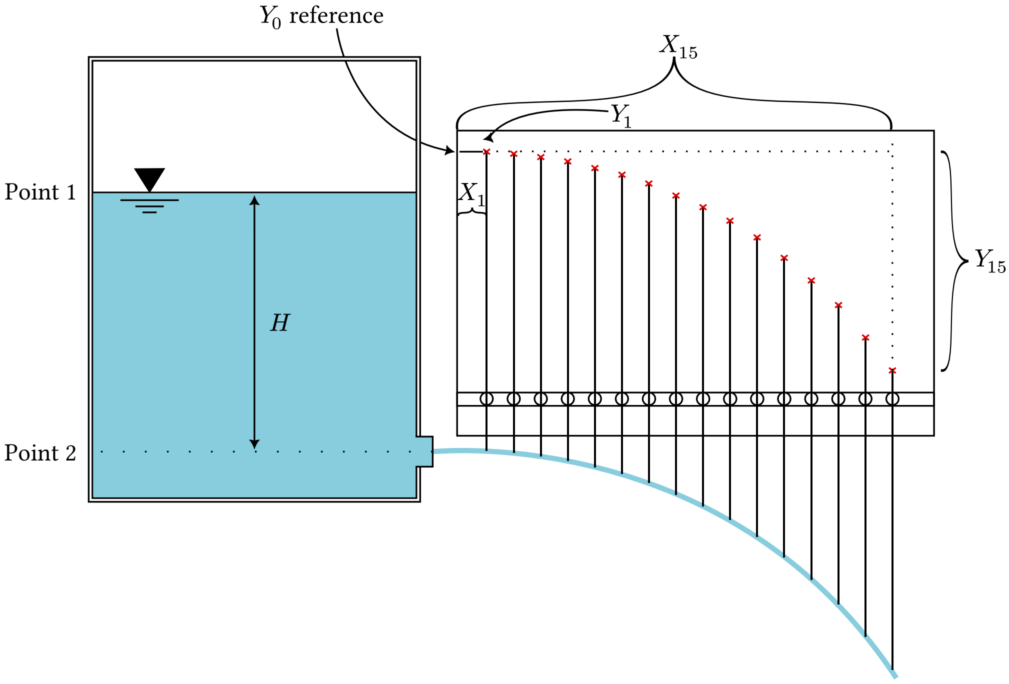

Figure 1: Visual representation of the experiment

H is the vertical distance between the surface of the fluid and the level of the orifice and the trajectory of the fluid is traced by needles equal in length attached to a board. The Y_0 is taken as the reference point which is the level of the top point of a needle when the bottom is at the same level of the orifice and is marked before the first needle.

1.1. Using the Bernoulli Equation

The Bernoulli equation is written as in Equation 1. Using that, we can determine the velocity of the leaving fluid by basing on points 1 and 2 in Figure 1. And this velocity is calculated as in Equation 2 by assuming constant pressure head.

$$\Delta h_{\text{kinetic}} + \Delta h_{\text{potential}} + \Delta h_{\text{pressure}} = 0 \tag{1}$$

Where:

- $\boldsymbol{\Delta h}_{\textbf{kinetic}}$ change in kinetic head $= \Delta v^2/2g$
- $\boldsymbol{\Delta h}_{\textbf{potential}}$ change in potential head $= \Delta z$
- $\boldsymbol{\Delta h}_{\textbf{pressure}}$ change in pressure head head $= \Delta P/\rho g$

$$v_{\text{th}} = \sqrt{2gH} \tag{2}$$

1.2. Using the Kinematic Equations

We can also assume that air resistance does not affect the trajectory of the fluid and treat it as a jet where there are two components, the v_x and the v_y. We can say that v_x is constant since there is no force acting with or against it, while v_y is affected by the downward acceleration of gravity.

Since the jet starts at zero y velocity, the vertical distance traveled can be computed by Equation 3. We can also compute the y velocity over time using Equation 4 and combining the two equations we get Equation 5.

$$Y = \frac{1}{2} v_y t \tag{3}$$

$$v_y = gt \tag{4}$$

$$Y = \frac{1}{2} g t^2 \tag{5}$$

1.3. Using the X and Y values of the Needles to find the Actual Velocity

The X's in Figure 1 are the distances of the needles from the reference point and the current point. For example X_i is the horizotal distance between the the edge of the board (the reference) and the position of the i$^{\text{th}}$ needle. The Y's are the same e.g., Y_i is the vertical distance from Y_0 and the upper tip of the i$^{\text{th}}$ needle.

Using this, we can compute the time for each needle interval from Equation 5:

$$\begin{aligned} t &= \sqrt{\frac{2Y}{g}} \\ t_1 &= \sqrt{\frac{2Y_1}{g}} \\ &\vdots \\ t_{15} &= \sqrt{\frac{2Y_{15}}{g}} \end{aligned} \tag{6}$$

Similarly, the horizontal travelling distance of the jet is:

$$\begin{aligned} X_1 &= v_x \cdot t_1 \\ &\vdots \\ X_{15} &= v_x \cdot t_{15} \end{aligned} \tag{7}$$

The actual velocity e.g., for point 1 can be found as in Equation 8.

$$v_{1,\text{actual}} = \frac{X_1}{t_1} = \frac{X_1}{\sqrt{\frac{2Y_1}{g}}} \tag{8}$$

1.4. Coefficient of Velocity

The coefficient of velocity, denoted as C_v, can be calculated in Equation 9.

$$C_v = \frac{\text{actual velocity}}{\text{theoretical velocity}} \tag{9}$$

The theoretical velocity is the one determined in the bernoulli equation in Equation 2, and the actual velocity is the one determined from the X and Y values of the needles in Equation 8.

$$
\begin{aligned}
C_v &= \frac{X_1 / \sqrt{\frac{2Y_1}{g}}}{\sqrt{2gH}} \\
&= \frac{X_1}{\sqrt{2Y_1/g} \cdot \sqrt{2gH}} \\
&= \frac{X_1}{2\sqrt{Y_1 H}}
\end{aligned} \tag{10}
$$

Thus various values for C_v can be found for different H.

1.5. Coefficient of Discharge

Similar to Equation 9, the coefficient of discharge, denoted as C_d, can be calculated in Equation 11

$$
C_d = \frac{\text{actual volumetric flowrate}}{\text{theoretical volumetric flowrate}} = \frac{Q_{\text{act}}}{Q_{\text{th}}} \tag{11}
$$

The actual flowrate can be determined by measuring the volume of fluid over a measured amount of time e.g., a beaker placed at the end of the trajectory with a stopwatch for measuring time.

$$
Q_{\text{act}} = \frac{\text{volume measured}}{\text{time measured}} \tag{12}
$$

The theoretical flowrate can be determined using the cross-sectional area of the orifice and the formula for velocity as stated in Equation 2.

$$
\begin{aligned}
Q_{\text{th}} &= A v_{\text{th}} \\
A &= \frac{\pi d^2}{4} \\
Q_{\text{th}} &= \frac{\pi d^2}{4} \cdot \sqrt{2gH}
\end{aligned} \tag{13}
$$

Therefore the formula for C_d is,

$$
C_d = \frac{Q_{\text{act}}}{\frac{\pi d^2}{4} \cdot \sqrt{2gH}}. \tag{14}
$$

In the experiment, you will observe that the Q_{act} is always lower than Q_{th} this is because of the *vena contracta* as shown in Figure 2 wherein after the leaving the orifice, the fluid stream narrows further, and as the stream expands again, there is energy loss leading to a smaller value of flowrate than the theoretical. Another reason for the flowrate minimization is the energy loss due to the viscosity of the fluid

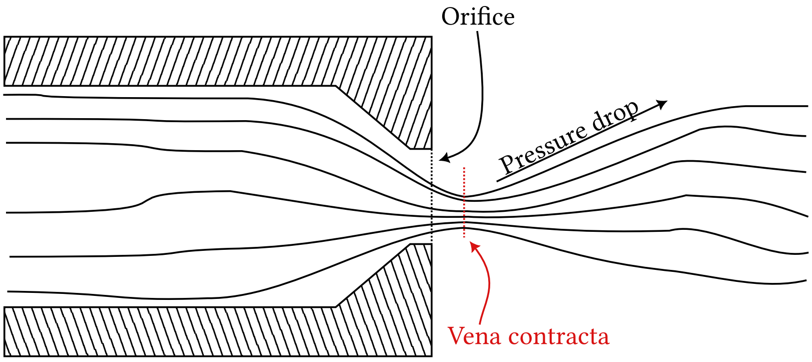

Figure 2: Visualization of the vena contracta.

1.6. Experiment Procedures according to the manuscript

1. Clip on a graph paper on the probe board behind the probes.
2. Place the apparatus on the Bench and adjust for leveling.
3. Connect the Bench outlet to the apparatus inlet.
4. Adjust the overflow pipe to obtain a required level in the tank.
5. Open the water supply valve to obtain a steady flow with minimum overflow.
6. Wait until the water level in the tank and jet profile is stable before adjusting the tips of the probes to be in line with the center of the jet.
7. Record the tip of the probe profile (upper tips) as well as the $Y = 0$ mark.
8. Record the volume of flow using a stop watch and the bench measuring tank or measuring cup.

1.7. Blank Data Sheet

	Experiment No.				
	1	2	3	4	5
Water level H, mm	410	390	370	350	200
Volume, L	2	2	2	2	2
Time, s					
Flow rate, m³/s					
Distance from graph, mm					
$X_1 = 50, Y_1 =?$					
$X_1 = 100, Y_2 =?$					
$X_1 = 150, Y_3 =?$					
$X_1 = 200, Y_4 =?$					
$X_1 = 250, Y_5 =?$					
$X_1 = 300, Y_6 =?$					
$X_1 = 350, Y_7 =?$					
$X_1 = 400, Y_8 =?$					
$X_1 = 450, Y_9 =?$					
$X_1 = 500, Y_{10} =?$					
Distance from graph, mm					
$C_{v,1}$					
$C_{v,2}$					
$C_{v,3}$					
$C_{v,4}$					
$C_{v,5}$					
$C_{v,6}$					
$C_{v,7}$					
$C_{v,8}$					
$C_{v,9}$					
$C_{v,10}$					
Coefficient of discharge					
C_d					