T.C.
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ESE – 40… ENERGY SYSTEMS LABORATORY -…
Flow Measurement Experiment Report

Student No :
Name-Surname :
Experiment Date :
Grade :

2.5 Flow Measurement Experiment

2.5.1 Objective

The main objective of this experiment is to obtain the coefficient of discharge from experimental data by utilizing venture meter and, also the relationship between Reynolds number and the coefficient of discharge.

2.5.2 Introduction

There are many different meters used to measure fluid flow: the turbine-type flow meter, the rotameter, the orifice meter, and the venturi meter are only a few. Each meter works by its ability to alter a certain physical property of the flowing fluid and then allows this alteration to be measured. The measured alteration is then related to the flow. The subject of this experiment is to analyze the features of certain meters.

2.5.3 Theory

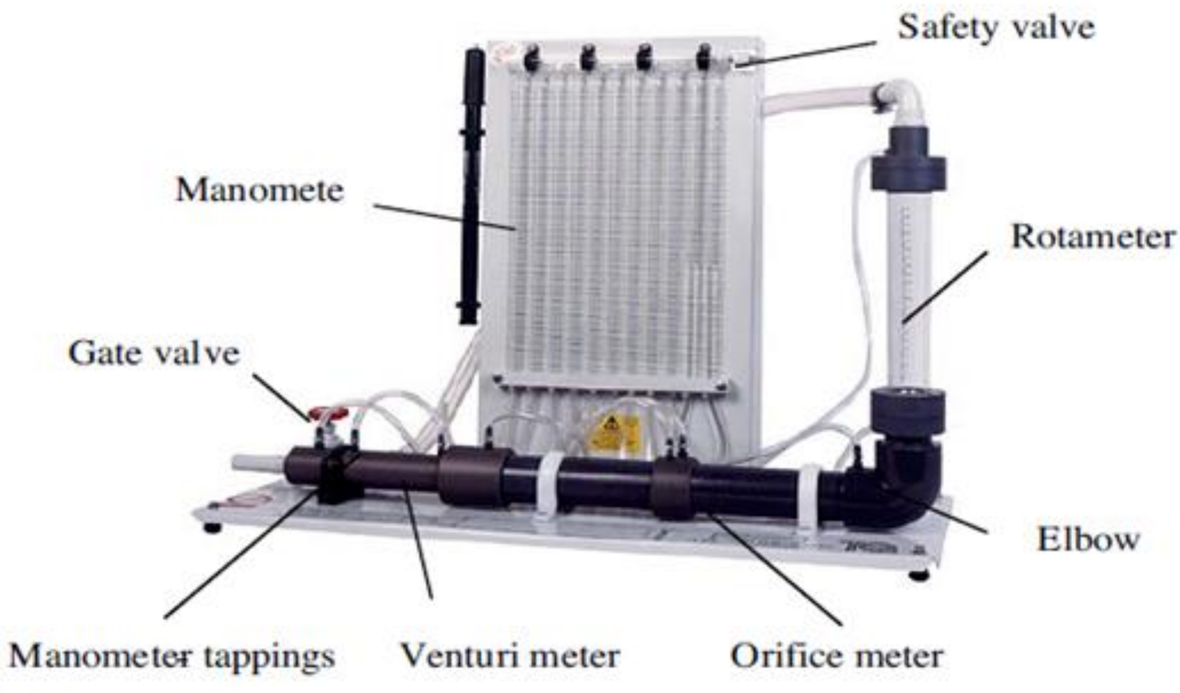


Figure 2.2.1. Flow measurement apparatus

The flow measurement apparatus consists of a water loop as shown above figure. The supple line is connected to a gravimetric hydraulic bench. The flow rate controlled by a gate valve located at the discharge side of the hydraulics bench. A venturi meter, wide-angled diffuser, orifice meter and rotameter are arranged in series. Pressure taps across each device are connected to vertical manometer tubes located on a panel at the rear of the apparatus. The discharge from the apparatus is returned to the hydraulics bench.

2.5.3.1 Venturi Meter

A venturi meter is a measuring or also considered as a meter device that is usually used to measure the flow of a fluid in the pipe. A Venturi meter may also be used to increase the velocity of any type fluid in a pipe at any particular point. It basically works on the principle of Bernoulli's Theorem. The pressure in a fluid moving through a small cross section drops suddenly leading to an increase in velocity of the flow. The fluid of the characteristics of high pressure and low velocity gets converted to the low pressure and high velocity at a particular point and again reaches to high pressure and low velocity. The point where the characteristics become low pressure and high velocity is the place where the venturi flow meter is used.

The Venturi meter is constructed as shown in Figure 2.2.2. It has a constriction within itself. The pressure difference between the upstream and the downstream flow, Δh, can be found as a function of the flow rate. Applying Bernoulli's equation to points ① and ② of the Venturi meter and relating the pressure difference to the flow rate yields.

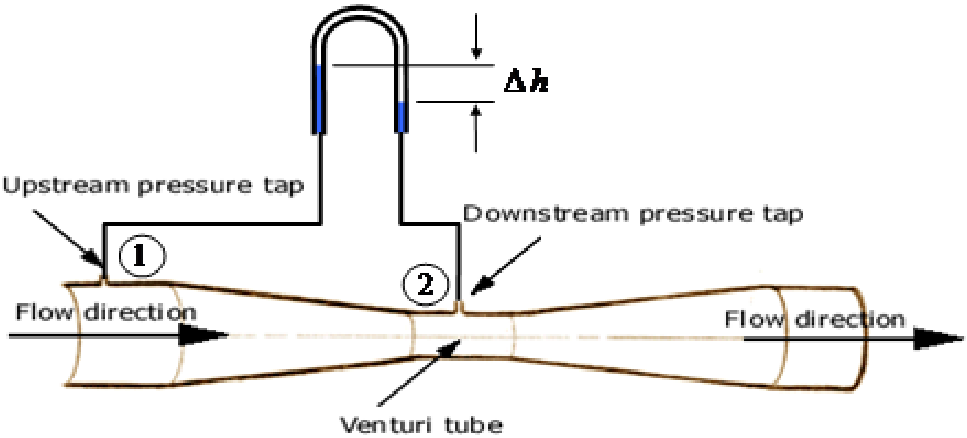


Figure 2.2.2. Venturi meter

Assume incompressible flow and no frictional losses, from Bernoulli's Equation

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 \qquad (2.2.1)$$

Use of the continuity Equation $Q = A_1V_1 = A_2V_2$, Equation (2.2.1) becomes

$$\frac{P_1 - P_2}{\gamma} + Z_1 - Z_2 = \frac{V_2^2}{2g}\left[1 - \left(\frac{A_2}{A_1}\right)^2\right] \qquad (2.2.2)$$

$$V_2 = \frac{1}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{2g\left(\frac{P - P_2}{\gamma} + (Z_1 - Z_2)\right)} \qquad (2.2.3)$$

Theoretical

$$Q_{theo} = A_2 V_2 = \frac{A_2}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}} \sqrt{2g\left(\frac{P_1 - P_2}{\gamma} + (Z_1 - Z_2)\right)} \quad (2.2.4)$$

The term $\frac{P_1 - P_2}{\gamma} + (Z_1 - Z_2)$ represents the difference in piezo metric head (Δh) between the two sections 1 and 2. The above expression for V_2 is obtained based on the assumption of one-dimensional frictionless flow. Hence the theoretical flow can be expressed as

$$Q_{theo} = A_2 V_2 = \frac{A_2}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}} \sqrt{2g(\Delta h)} \quad (2.2.5)$$

Thus,

$$Q_{theo} = \sqrt{\frac{2g\Delta h}{\left(\frac{1}{A_2^2} - \frac{1}{A_1^2}\right)}} \quad (2.2.6)$$

Because of the above assumptions, the actual flow rate, Q_{act} differs from Q_{theo} and the ratio between them is called the discharge coefficient, C_d which can be written as

$$C_d = \frac{Q_{act}}{Q_{theo}} \quad (2.2.7)$$

The value of C_d differs from one flowmeter to the other depending on the flowmeter geometry and the Reynolds number. The discharge coefficient is always less than due to various losses(friction losses, area contraction etc.).

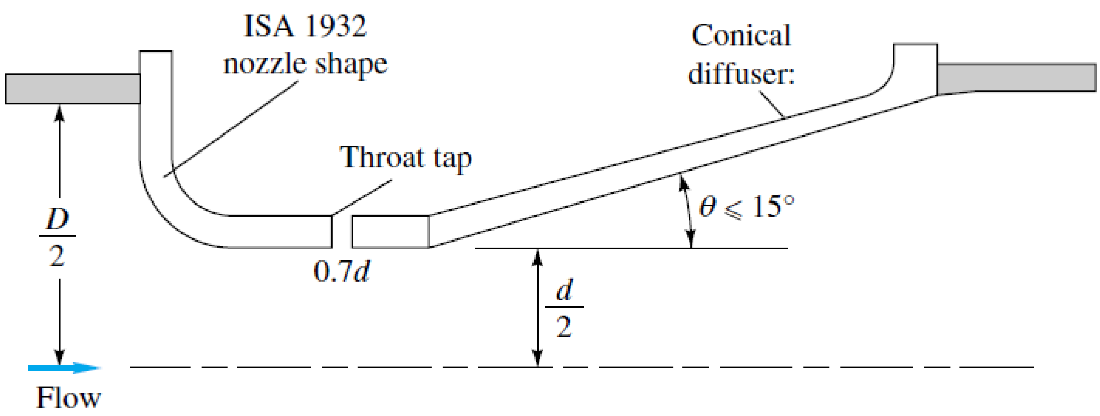


Figure 2.2.3. International standard shapes for venture nozzle

The modern venturi nozzle, Fig. 2.2.3, consists of an ISA 1932 nozzle entrance and a conical expansion of half-angle no greater than 15°. It is intended to be operated in a narrow Reynolds-number range of 1.5 x 10^5 to 2 x 10^6. The co-efficient of discharge is 0.95-0.98 for venturi meter.

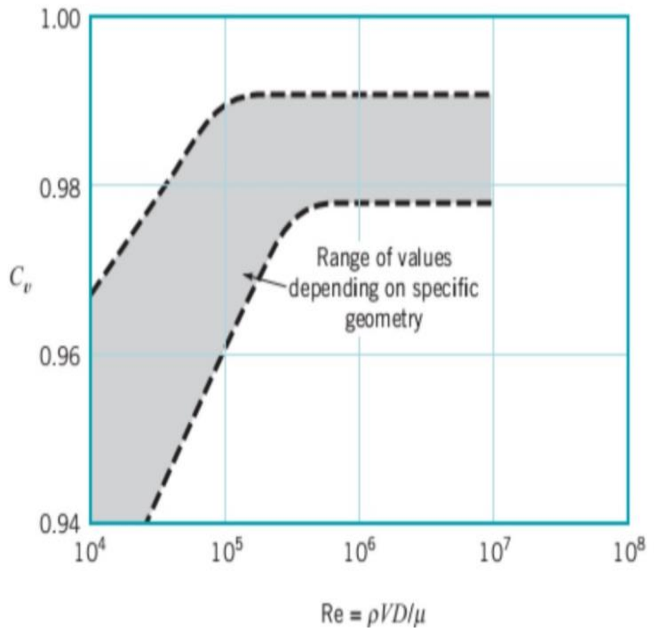


Figure 2.5.4. . The co-efficient of discharge of a venturi meter

2.5.3.2 The Orifice Meter

The orifice meter consists of a throttling device (an orifice plate) inserted in the flow. This orifice plate creates a measurable pressure difference between its upstream and downstream sides. This pressure is then related to the flow rate. Like the Venturi meter, the pressure difference varies directly with the flow rate. The orifice meter is constructed as shown in Figure 2.2.5.

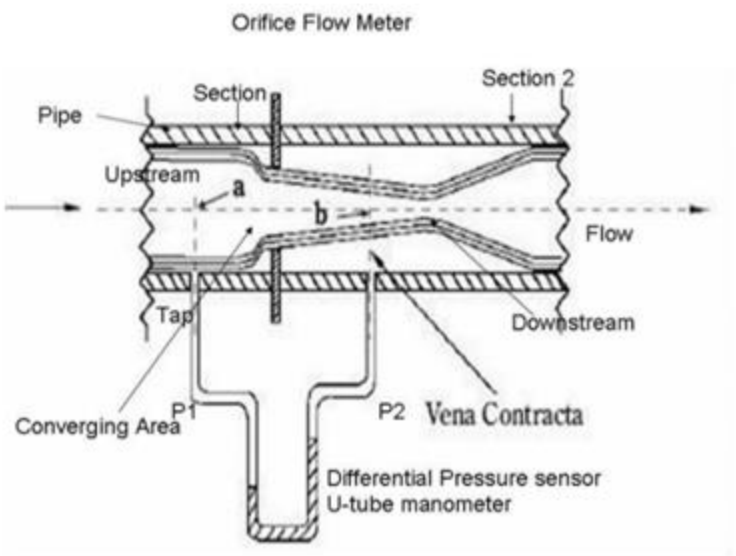


Figure 2.5.5. Cutaway view of the orifice meter

The co-efficient of discharge is 0.62-0.67 for orifice meter.

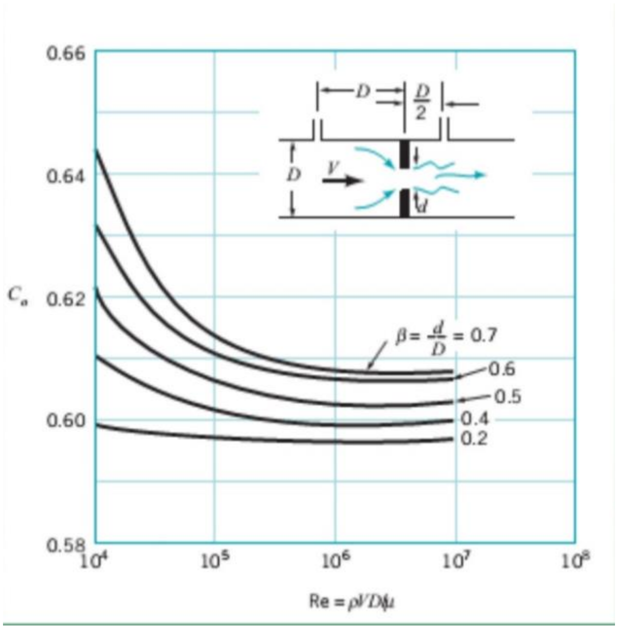


Figure 2.2.6. The co-efficient of discharge of a orifice meter

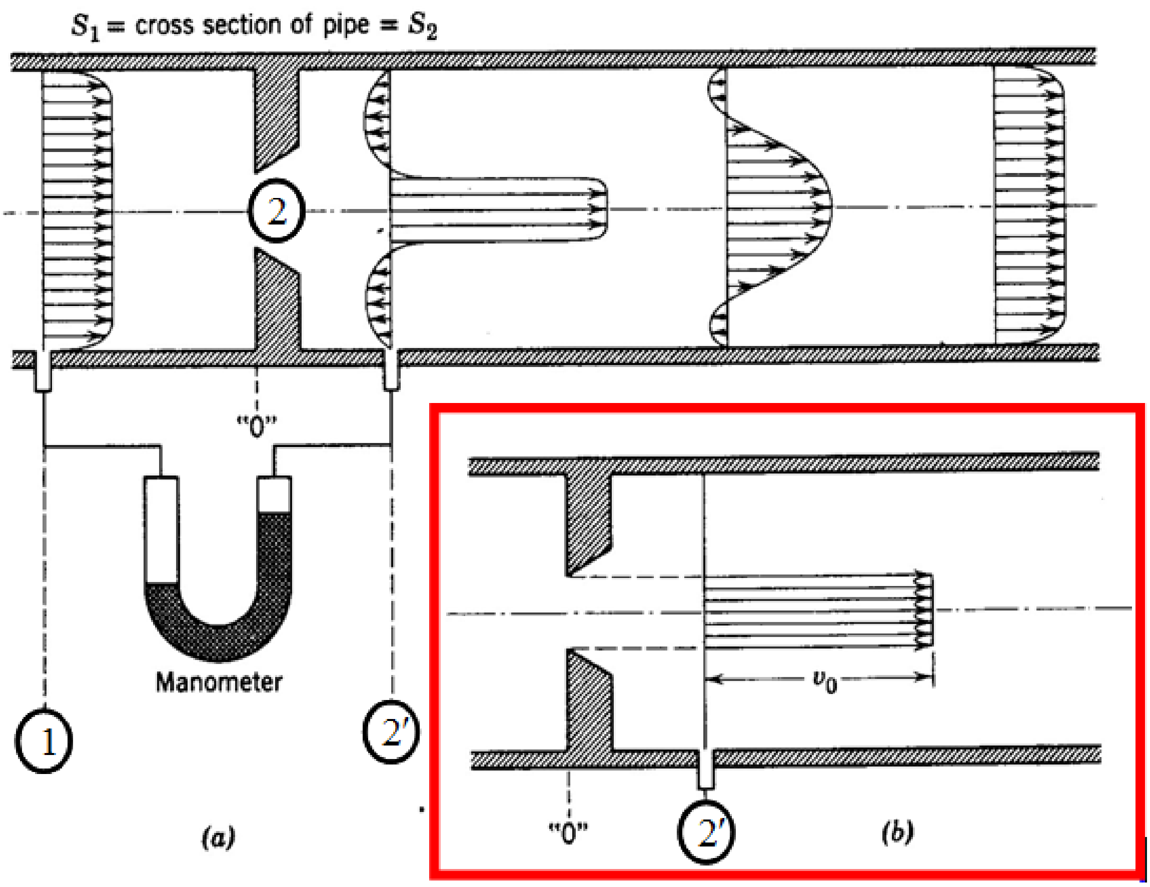
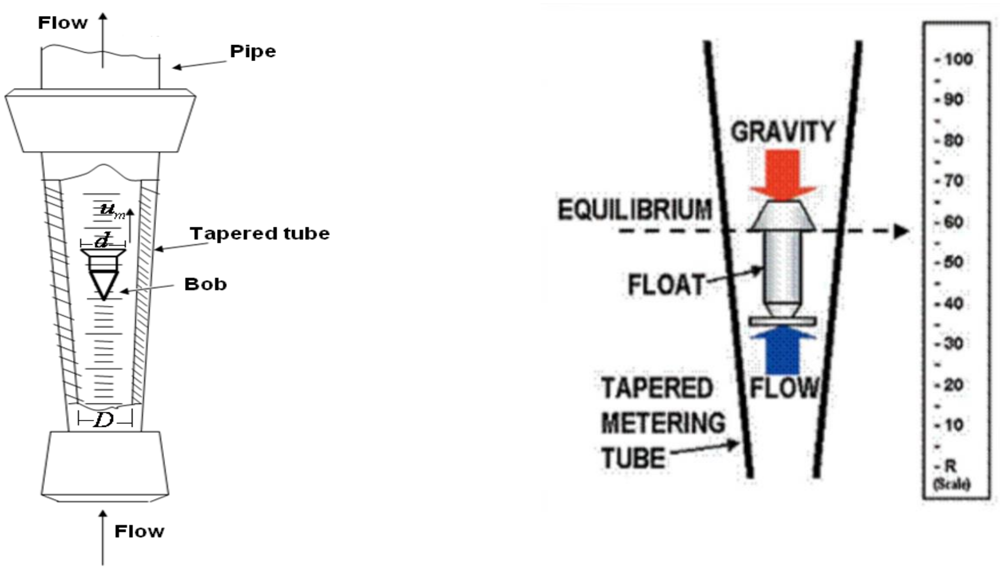


Figure 2.5.7. (a) The approximate velocity profiles at several planes near a sharp-edged orifice plate. Note: the jet emerging from the hole is somewhat smaller than the hole itself; in highly turbulent flow the jet necks down to a minimum cross section at the vena contracta. Note that there is some backflow near the wall. **(b)** It is assumed that the velocity profile at ② is given by the approximate profile shown. It is also assumed that the velocity profile at ① is uniform. From boundary layer theory, the pressure of the plug flow at ② is transmitted across the (assumed stagnate) interval from the plug to the pressure port

2.5.3.3 The Variable Area Meter (Rotameter)

A rotameter consists of a gradually tapered glass tube mounted vertically in a frame with the large end up. Fluid enters the tube from the bottom. As it enters, it causes the float to rise to a position of equilibrium. The position of equilibrium is at the point where the weight of the float is balanced by the weight of the fluid it displaces (the buoyant force exerted on the float by the fluid) and the pressure due to velocity (dynamic pressure).

The higher the float position the greater the flow rate. Note that as the float rises, the annular area formed between the float and the tube increases. Maximum flow is at maximum annular area or when the float is at the top of the tube. Minimum area, of course, represents minimum flow rate and is when the float is at the bottom of the tube.



(a) **(b)**

Figure 2.5.8. **(a, b)** Rotameter

In balance conditions, the flow rate is expressed by the following formula:

$$Q = C_d (A_T - A_F) = \sqrt{\frac{2V_f(\rho_f - \rho)}{A_f \rho}} \quad (2.2.8)$$

where

C_d = coefficient of efflux
A_t = pipe section
A_f = maximum section of the float
V_f = Volume of the float
ρ_f = density of the float
ρ = density of fluid

CALCULATIONS AND DATAS

1. Calculation of the coefficient of efflux of the calibrated diaphragm (Orifice meter)

- Find the volumetric flow for each measurement by using the Equation 1:

$$\mathbf{Q_{vol}} = \frac{\mathbf{V}}{\mathbf{t}} \quad \text{(Eq. 1)}$$

Where

V: is the volume of the water output accumulated in the storage tank

t: is the time it takes to fill the selected volume

- Find the theoretical flow rate of orifice meter for each measurement by using the Equation 2:

$$\boldsymbol{Q_{theo,orifice}} = \frac{\boldsymbol{A_2}}{\sqrt{\boldsymbol{1-\beta^4}}}\sqrt{\boldsymbol{2g\Delta h_{1,2}}} \quad \text{(Eq. 2)}$$

Where:
D=18.3 mm d=14mm (orifice meter)
C_d= coefficient of discharge
$\beta = d/D$
$A_1 = \pi D^2/4$ (pipe section)
$A_2 = \pi d^2/4$ (restriction section)
$\Delta h_{1,2} = h_1 - h_2$ (load loss)
$g=9.81\ m/s^2$ (gravitational acceleration)

- Find the coefficient of efflux (or the discharge coefficient),C_d by using the Equation 3:

$$\boldsymbol{C_d} = \frac{\boldsymbol{Q_{actual}}}{\boldsymbol{Q_{theoretical,orifice}}} \quad \text{(Eq. 3)}$$

(Note that the volumetric flow rate is the actual flow rate so $Q_{actual}=Q_{vol}$)

- Draw a relationship between the volumetric flow rate (Q_{vol}) in y – axis and the square root of the load loss **(orifice meter)** in x – axis

Q_{rot} (L/h)	Volume (L)	Time	Q_{vol} (m^3/s)	H_1 (mm)	H_2 (mm)	$\sqrt{\Delta H_{1,2}}$ (m)	H_3 (mm)	H_4 (mm)	$\sqrt{\Delta H_{3,4}}$ (m)	H_5 (mm)	H_6 (mm)	$\sqrt{\Delta H_{5,6}}$ (m)
90	10	7’56” (7 min 56 sec)		248	246		488	483		447	315	
240	10	2’48”		252	240		493	455		422	286	
370	10	1’38”		254	222		495	385		397	262	
440	10	1’25”		260	210		502	350		372	232	
560	10	1’5”		264	166		507	275		336	203	

2. Calculation of the coefficient of efflux of the venturi meter

- Find the volumetric flow for each measurement by using the Equation 4:

$$\mathbf{Q_{vol}} = \frac{\mathbf{V}}{\mathbf{t}} \qquad \text{(Eq. 4)}$$

Where

V: is the volume of the water output accumulated in the storage tank

t: is the time it takes to fill the selected volume

- Find the theoretical flow rate of orifice meter for each measurement by using the Equation 5:

$$\boldsymbol{Q_{theo,venturi}} = \frac{\boldsymbol{A_2}}{\sqrt{\mathbf{1} - \boldsymbol{\beta^4}}} \sqrt{\mathbf{2}\boldsymbol{g}\Delta\boldsymbol{h_{3,4}}} \qquad \text{(Eq. 5)}$$

Where:
D=20 mm d=10mm (venturi meter)
C_d= coefficient of discharge
$\beta = d/D$
$A_1 = \pi D^2/4$ (pipe section)
$A_2 = \pi d^2/4$ (restriction section)
$\Delta h_{3,4} = h_3 - h_4$ (load loss)
$g = 9.81$ m/s^2 (gravitational acceleration)

- Find the coefficient of efflux (or the discharge coefficient),C_d by using the Equation 6:

$$\boldsymbol{C_d} = \frac{\boldsymbol{Q_{actual}}}{\boldsymbol{Q_{theoretical,venturi}}} \qquad \text{(Eq. 6)}$$

(Note that the volumetric flow rate is the actual flow rate so $Q_{actual}=Q_{vol}$)

- Draw a relationship between the volumetric flow rate (Q_{vol}) in y – axis and the square root of the load loss **(venturi meter)** in x – axis

$\% \ \mathbf{Error} = \frac{\mathbf{Q_{orifice}} - \mathbf{Q_{vol}}}{\mathbf{Q_{vol}}} \boldsymbol{x}\mathbf{100}$ (for orifice meter)

$\% \ \mathbf{Error} = \frac{\mathbf{Q_{venturi}} - \mathbf{Q_{vol}}}{\mathbf{Q_{vol}}} \boldsymbol{x}\mathbf{100}$ (for venturi meter)

$\% \ \mathbf{Error} = \frac{\mathbf{Q_{rotameter}} - \mathbf{Q_{vol}}}{\mathbf{Q_{vol}}} \boldsymbol{x}\mathbf{100}$ (for rotameter)

3. Calculate the load losses

Calculate the coefficients of discharges (c_d) for every part (orifice meter, venturi meter and rotameter).

4. Calibration of the variable area flowmeter

- Draw the calibration curvebased on the table below, the reading of the rotameter (on y-axis) against the measured actual volume flowrate (on x-axis).

$$Q_{vol} = \frac{V}{t}$$

5. Report

In your laboratory reports must have the followings;

a) Cover page.
b) All the necessary calculations using measured data.
c) Discussion of your results and a conclusion (Compare the Cd values and explain advantages and disadvantages etc. of three flow meters also even if you think the results are unexpected, explain the possible reasons)