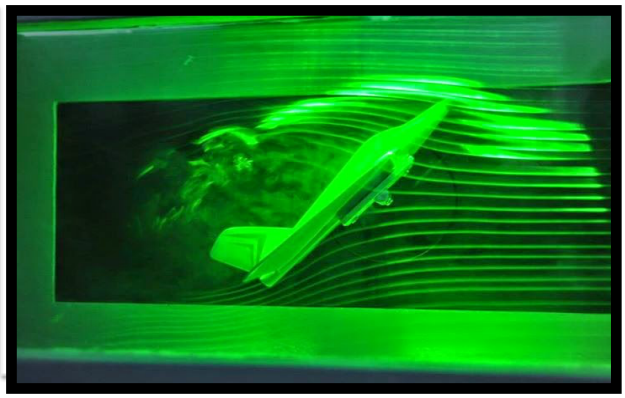
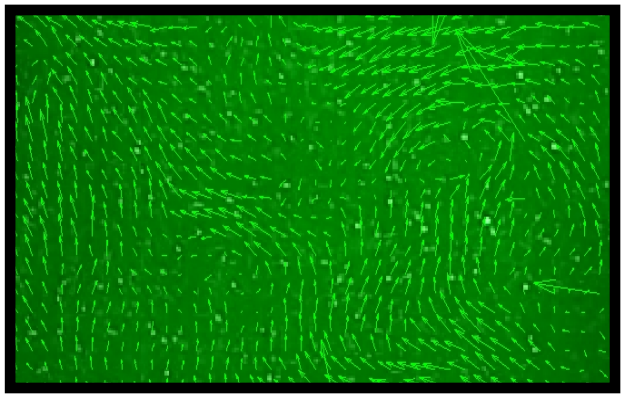
B.M.S.College of Engineering

(Autonomous Institute Under VTU, Bengaluru -19)

Department of Mechanical Engineering





Fluid Mechanics Laboratory Manual

Name	**:**.....
U.S.N	**:** .....
Sem/Sec	**:** .....

VISION

To become a centre of excellence in educating students to become successful Mechanical Engineers

MISSION

- ➢ To empower the students with fundamentals for successful career in the field of Mechanical Engineering
- ➢ To continue their education through post-graduation, research & development
- ➢ To provide service to the society

COURSE OUT COMES

1	Students will be able to distinguish and calibrate different flow measuring devices.
2	Students will be able to characterise the flow field based on the Reynolds number.
3	Students will be able to measure the pressure distribution on stream lined and bluff bodies.
4	Students will be able to calibrat the friction in ducts
5	Students will be able to visualize the flow around the objects using flow visualisation techniques.

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Certificate

This is to certify that Ms./Mr. _____ bearing USN _____is the student of III Semester B.E.(Mech.), BMS College of Engineering, affiliated to **Visvesvaraya Technological University, Belgaum** has successfully completed the lab work connected with the Fluid Mechanics Lab as prescribed by the college during the Academic year ____-____.

Total Marks obtained

Staff Incharge : _____ Prof.& Head

Date : _____ Dept. of Mechanical Engg.

List of Experiments

Part A

Hydraulics Lab

1. Calibration of V- Notch.
2. Calibration of Venturimeter.
3. Calibration of Orifice Meter.
4. Estimation of friction in pipes.
5. Reynolds Experiment
6. Bernoullis Experiment
7. Hele Shaw Apparatus

Part B

Wind Tunnel Lab

1. Velocity and Total Pressure Measurement using Pitot tube.
2. Static Pressure Measurement using Projection Manometer.
3. Estimation of Pressure distribution of symmetric airfoil.
4. Estimation of Pressure distribution of Cambered airfoil.
5. Estimation of Pressure distribution on cylinder.
6. Estimation of Pressure distribution on sphere.
7. Flow Visualization on airfoil, cylinder and sphere.

Fluid Flow Measurements

Introduction:

As the fluid flow relative to the objects either internally or externally, measurements of properties like pressure, velocity, mass flow rate or discharge are of primarily important. This can be achieved by

- Pitot Tubes (Static and Total) for Velocity Measurement.
- Manometers for Pressure Measurement.
- Notches and Weirs for measuring discharge.
- Venturimeter and Orifice Meter for discharge.

The rate of a fluid through a pipe or duct or interflow is measured by instruments like Venturimeter, Orifice meter etc., whereas through an open channel the rate of flow is measured by notches and wires. Pressure in the fluid is measure by manometer, barometer etc.

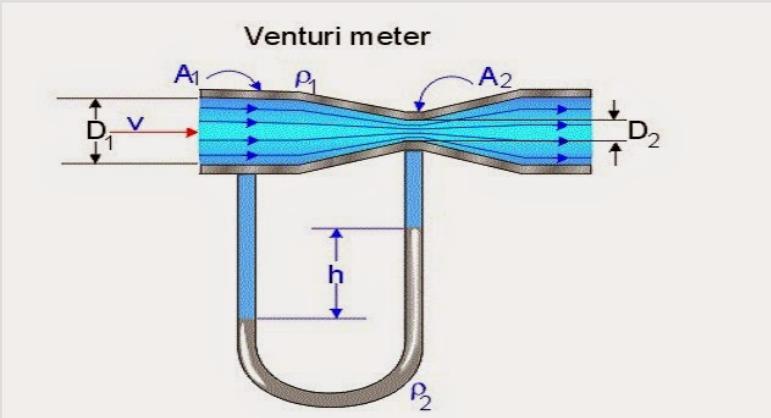
In this lab students get exposed to learning how to measure mass flow rate or volume flow rate, velocity and pressure using pitot tubes and manometers and how to visualise for over streamlined and bluff bodies.

Mass Flow rate meters or Discharge measuring instruments:

Venturi meter:

A Venturi meter is a device used for measuring the rate of flow of fluid flowing through a pipe. It consists of three parts as shown in Figure 1:

- A short converging part
- Throat
- Diverging part.



Expression for rate of flow through Venturi meter:

Consider a Venturi meter fitted in a horizontal pipe through which a fluid is flowing (say water), as shown in figure below

Let d_1= diameter at inlet or at section (1)

P_1= pressure at section (1)

v_1 = velocity of fluid at section (1),

a= area at section (1) = $\frac{\pi}{4}d_1^2$, and d_2, p_2, v_2, a_2, are corresponding values at section (2).

Applying Bernoulli's equation at sections (1) and (2), we get

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2$$

As pipe is horizontal, hence

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}=\frac{P_2}{\rho g}+\frac{V_2^2}{2g} \quad \text{Or} \quad \frac{P_1-P_2}{\rho g}=\frac{V_2^2}{2g}-\frac{V_1^2}{2g}$$

But $\frac{P_1-P_2}{\rho g}$ is the difference of pressure heads at section 1 and 2 and it is equal to h or $\frac{P_1-P_2}{\rho g}=h$. Substituting the value of $\frac{P_1-P_2}{\rho g}$ in the above equation, we get

$$h=\frac{V_2^2-V_1^2}{2g} \quad (1)$$

Now applying continuity equation between section 1 and 2

$$a_1v_1=a_2v_2 \text{ Or } \quad v_1=\frac{a_1-v_2}{a_1}$$

Substituting this value of v_1 in equation (1)

$$h=\frac{V_2^2}{2g}-\left(\frac{\frac{a_2v_2}{a_1}}{2g}\right)^2=\frac{V_2^2}{2g}\left[1-\frac{a_2^2}{a_1^2}\right]=\frac{V_2^2}{2g}\left[\frac{a_1^2-a_2^2}{a_1^2}\right]$$

$$v_2^2=2gh\frac{a_1^2}{a_1^2-a_2^2}$$

$$v_2=\sqrt{2gh\frac{a_1^2}{a_1^2-a_2^2}}=\frac{a_1}{\sqrt{a_1^2-a_2^2}}\sqrt{2gh}$$

Since Discharge is given by , $Q=a_2v_2$

$$Q=a_2\frac{a_1}{\sqrt{a_1^2-a_2^2}}\times\sqrt{2gh}=\frac{a_1a_2}{\sqrt{a_1^2-a_2^2}}\times\sqrt{2gh} \text{--- (2)}$$

Equating (2) gives the discharge under ideal conditions and is called, theoretical discharge. Actual discharge will be less than theoretical discharge.

$$Q_{act} = c_d \times \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh} \text{--- (3)}$$

where $c_d$is co−efficient of venturimeter and its value is less than 1.

Value of 'h' given by differential U-tube manometer

Case I. Let the differential manometer contains a liquid which is heavier than the liquid flowing through the pipe.

Let $s_h$specific gravity of heavier liquid

$s_o$specific gravity of liquid flowing through pipe.

X= Difference of the heavier liquid column in U-tube Then $h = \left[\frac{s_h}{s_h}\right]$ --- (4)

Case II. If the differential manometer contains a liquid which is lighter than the liquid flowing through the pipe, the valve of h is given by $h = \left[1 - \frac{s_l}{s_o}\right]$

where s_l specific gravity of lighter liquid in U tube

s_o specific gravity of fluid flowing through the pipe

X= Difference of the heavier liquid columns in U-tube

Case III. Inclined Venturimeter with Differential U-tube manometer. The above two cases are given for a horizontal Venturimeter. This case is related to incline Venturimeter having different U-tube manometer. Let the differential manometer. Let the differential manometer contains heavier liquid then h is given as

$$h = \left(\frac{P_1}{\rho g} + Z_1\right) - \left(\frac{P_2}{\rho g} + Z_2\right) = x\left[\frac{s_h}{s_o} - 1\right] \text{ ----- (6)}$$

Case IV. Similarly, for inclined Venturimeter in which differential manometer contains a liquid which is lighter than the liquid flowing through the pip, the value of k is given as

$$h = \left(\frac{P_1}{\rho g} + Z_1\right) - \left(\frac{P_2}{\rho g} + Z_2\right) = x\left[1 - \frac{s_h}{s_o}\right] \text{ ----- (7)}$$

Orifice meter or Orifice plate

It is a device used for measuring the rate of flow of a liquid through a pipe. It is a cheaper device as compared to Venturimeter. It also works on the same principal as that of Venturimeter. It consists of a flat circular plate which has a circular sharp edged hole called orifice, which is concentric with the pipe. The orifice diameter is kept generally 0.5 times the diameter if the pipe. Through it may vary from 0.4 to 0. 8 times the pipe diameter.

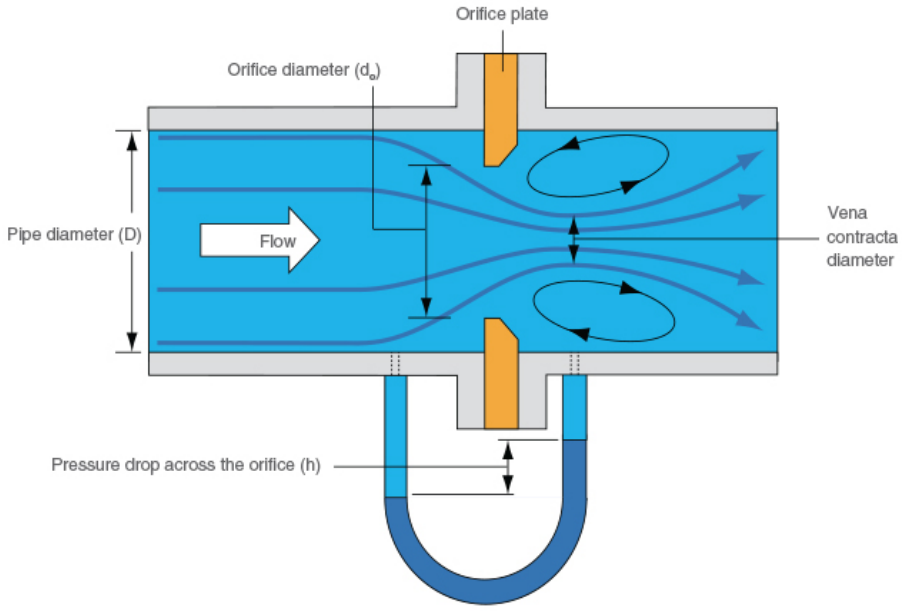


Fig. 4.2.8 An orifice plate with vena contracta

A differential manometer is connected at section (1), which is at a distance of about 1.5 to 2.0 times the pipe diameter upstream from the orifice plate, and at section (2), which is at a distance of about half the diameter of the orifice on the downstream side from the orifice plate.

Let P_1= pressure at section (1), v_1 = velocity at section (1), a= area of pipe at section (1) and p_2, v_2, a_2, are corresponding values at section (2). Applying Bernoulli's equation at sections (1) and (2). Applying Bernoulli's Principle we get

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2$$

$$\text{Or}\quad \left(\frac{P_1}{\rho g}+Z_1\right)-\left(\frac{P_2}{\rho g}+Z_2\right)=\frac{V_2^2}{2g}-\frac{V_1^2}{2g}$$

$$\text{But}\quad \text{Differential head} = h = \left(\frac{P_1}{\rho g}+Z_1\right)-\left(\frac{P_2}{\rho g}+Z_2\right)$$

$$h = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} \quad \text{Or} \quad 2gh = V_2^2 - V_1^2$$

Or $$V_2 = \sqrt{2gh + V_1^2} \text{--- (i)}$$

Now section (2) is at the vena contracta and a_2 represents the area at the vena contracta. If a_0 is the area of orifice then, we have$C_c = \frac{a_2}{a_o}$ Where C_c= Co-efficient of contraction $a_2 = a_o \times C_c$

By continuity equation, we have $a_1 v_1 = a_2 v_2$ Or $v_1 = \frac{a_2}{a_1} v_2 = \frac{a_o C_c}{a_1} v_2$

Substituting the values of v_1 in equation (i), we get

$$v_2 = \sqrt{2gh + \frac{a_o^2 C_c^2 v_2^2}{a_1^2}}$$

Or $$v_2^2 = 2gh + \left(\frac{a_o}{a_1}\right)^2 C_c v_2^2() v_2^2 \times \left[1 - \left(\frac{a_o}{a_1}\right)^2 C_c^2\right] = 2gh$$

$$v_2 = \frac{\sqrt{2gh}}{\sqrt{1 - \left(\frac{a_o}{a_1}\right)^2 C_c^2}}$$

The discharge $Q = v_2 \times a_2 = v_2 \times a_o C_c a_2 = a_o C_c \frac{a_o C_c \sqrt{2gh}}{\sqrt{1 - \left(\frac{a_o}{a_1}\right)^2 C_c^2}}$ --- (iv)

The above expression is simplified by using $C_d = C_c \frac{\sqrt{1 - \left(\frac{a_o}{a_1}\right)^2}}{\sqrt{1 - \left(\frac{a_o}{a_1}\right)^2 C_c^2}}$

Hence we get $C_c = C_d \frac{\sqrt{1 - \left(\frac{a_o}{a_1}\right)^2 C_c^2}}{\sqrt{1 - \left(\frac{a_o}{a_1}\right)^2}}$

Substituting this value of $C_c$in equation (iv). We get

$$Q = a_o \times C_d \frac{\sqrt{1-\left(\frac{a_o}{a_1}\right)^2 C_c{}^2}}{\sqrt{1-\left(\frac{a_o}{a_1}\right)^2}} \times \frac{\sqrt{2gh}}{\sqrt{1-\left(\frac{a_o}{a_1}\right)^2 C_c{}^2}}$$

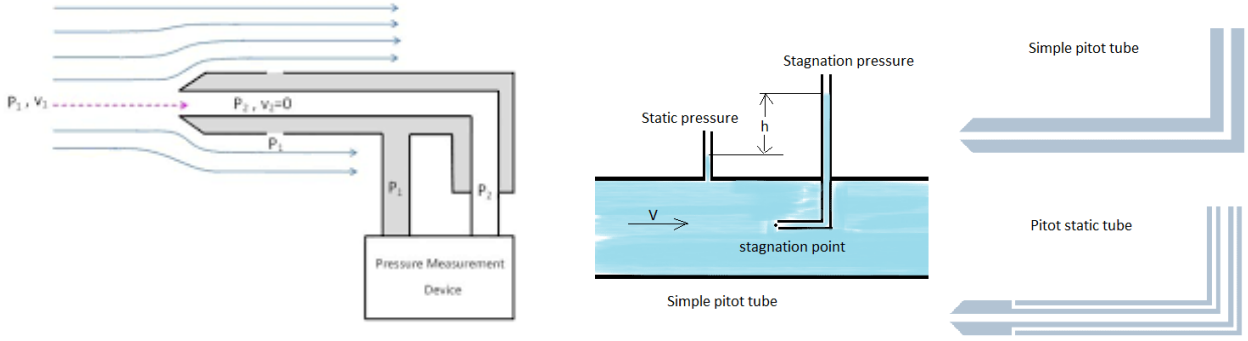
$$\frac{C_d a_o \sqrt{2gh}}{\sqrt{1-\left(\frac{a_o}{a_1}\right)^2}} = \frac{C_d a_o a_1 \sqrt{2gh}}{\sqrt{a_1{}^2 - a_o{}^2}}$$

Where C_d=Co-efficient of discharge for orifice meter.

The co-efficient of discharge for orifice meter is much smaller than that for a Venturimeter.

Pitot-Tube

It is a device used for measuring the velocity of flow at any point in a pipe or a channel. It is based on the principle that if the velocity of flow at a point becomes zero, the pressure there is increased due to the conversion of the kinetic energy into pressure energy. In its simplest form, the Pitot-tube consists of a glass tube, bent at right angle as shown in figure below.



The lower end, which is bent through 90 is directed in the upstream direction as shown in Figure 3. the liquid rises up in the tube to the conversion of kinetic energy in to pressure energy. The velocity is determined by measuring the raise of liquid in the tube.

Consider two points (1) and (2) at the same level in such a way that (2) is just at the inlet of the Pitot-tube and point (1) is far away from the tube.

Let P_1= intensity of pressure at point (1)

v_1 = velocity of flow at (1)

P_2= pressure at section (2)

V_2 = velocity at point (1), which is zero

H= depth of tube in the liquid

h= rise of liquid in the tube above the free surface.

Applying Bernoulli's equations at point (1) and (2), we get

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2$$

But $Z_1 = Z_2$ as points (1) and (2) are on the same line and v_2 =0.

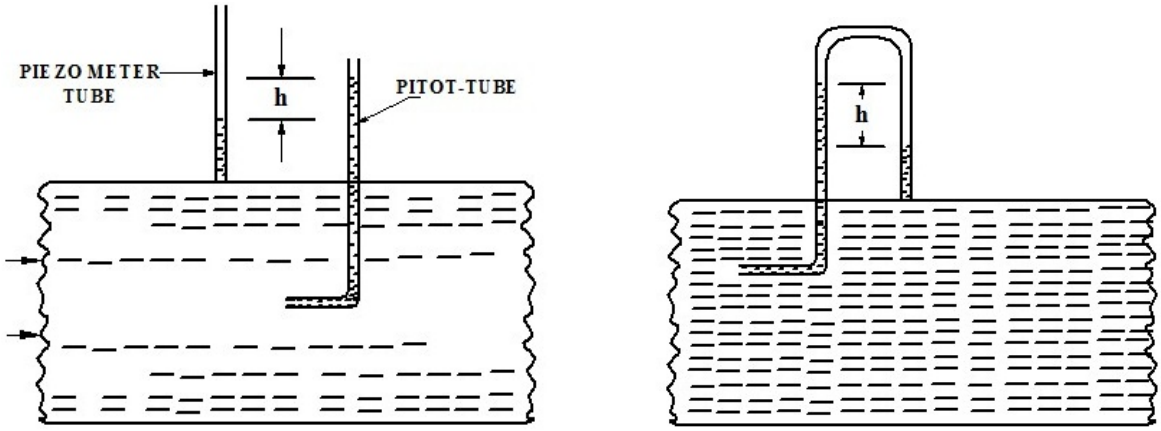
$\frac{P_1}{g}$= pressure head at (1) = H and $\frac{P_2}{g}$= pressure head at (2) = (h+H)

Substituting these values, we get $H+\frac{V_1^2}{2g}=(h+H)\ ;V_1=\sqrt{(2gh)}$

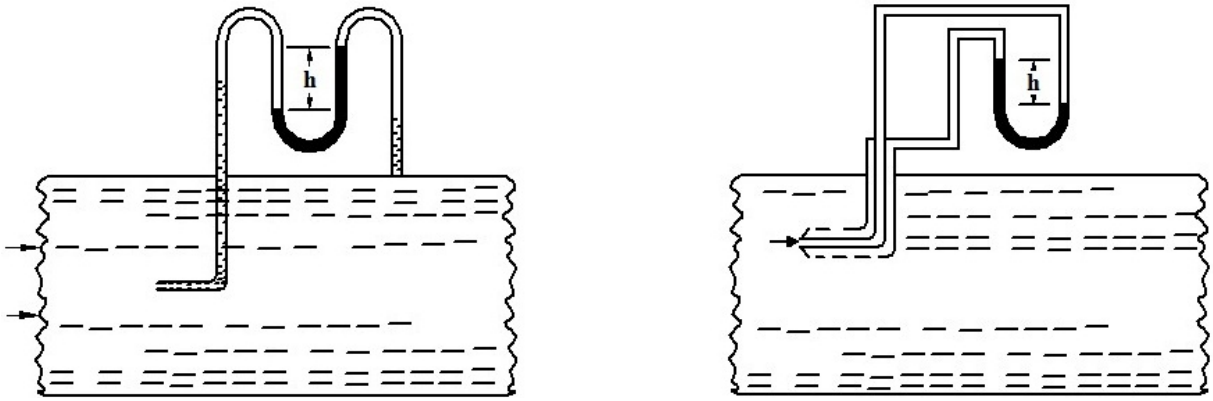
This is theoretical velocity. Actual velocity is given by $(v_1)_{act} = C_v\sqrt{2gh}$, Where C_v= Co-efficient of Pitot-tube

Velocity of flow in a pipe by Pitot-tube.

For finding the velocity at any point in a pipe by Pitot-tube, the following arrangements are adopted:



1. Pitot-tube along with a vertical piezometer tube as shown in Fig. (b).
2. Pitot-tube connected with piezometer tube as shown in Fig. (c).
3. Pitot-tube and vertical piezometer tube connected with a different U-tube manometer as shown in Fig. (d).



4. Pitot-static tube, which consists of two circular concentric tubes one the other with some annular space in between as shown in Fig. (e). The outlet of these two tubes are connected to
5. the different manometer where the difference of pressure head 'h' is measured by knowing the Difference of the levels of the manometer liquid say x. then $h = x\left[\frac{S_g}{S_o} - 1\right]$

Darcy-Equation for loss of head due to friction in pipes

Consider a a uniform pipe, having steady flow as shown in fig below. Let 1-1 and 2-2 are two sections of pipe.

Let P_1 = pressure intensity at section 1-1,

v_1 = velocity of flow at section 1-1,

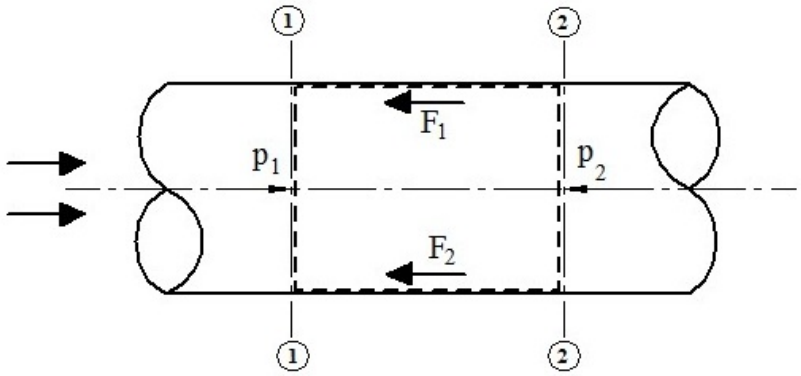
L = length of the pipe between section 1-1 and 2-2,

D = diameter of pipe,

F' = frictional resistance per unit wetted area per unit velocity,

H_f = loss of head due to friction,

And p_2, V_2 = are values of pressure intensity and velocity at section 2-2.



Applying Bernoulli's equation between sections 1-1 and 2-2,

Total head at 1-1 = Total head at 2-2 + loss of head due to friction between 1-1 and 2-2

Or $\frac{P_1}{g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{g} + \frac{V_2^2}{2g} + Z_2 + h_fButz_1 = z_2$as pipe is horizontal $V_1 = V_2$ as diameter of pipe is same at the two sections.

$$\frac{P_1}{\rho g} = \frac{P_2}{\rho g} + h_f \qquad \ldots \text{(i)}$$

But h_f is the head lost due to friction and hence intensity of pressure will be reduced in the direction of flow by frictional resistance.

Now frictional resistance = frictional resistance per unit wetted area per unit velocity × wetted area × velocity^2

or $F_1 = f' \times dL \times V^2$ [wetted area= d × L velocity = V=$V_1 = V_2$]

$= f' \times P \times L \times V^2$ [p d = Perimeter = P] … (ii)

The force acting in the fluid between sections 1-1 and 2-2 are:

1. Pressure force 1-1 = $p_1 \times A$

Where A= Area of pipe

2. Pressure at section 2-2 = $p_2 \times A$
3. Frictional force F_1 as shown in figure above.

Resolving all forces in the horizontal direction, we have

$$p_1 A - p_2 A - F_1 = 0$$

or $$(p_1 - p_2)A = F_1 = f' \times P \times L \times V^2 \qquad [p \text{ From (ii), } F_1 \text{ f'PLV}^2]$$

Or $$p_1 - p_2 = \frac{f' \times P \times L \times V^2}{A}$$

But from equation (i), $p_1 - p_2 = gh_f$

Equating the value of $(p_1 - p_2)$, we get

$$gh_f = \frac{f' \times P \times L \times V^2}{A}$$

or $$h_f = \frac{f'}{g} \times \frac{p}{A} \times L \times V^2 \qquad \ldots \text{(iii)}$$

In equation (iii), $\frac{P}{A} = \frac{Wettedperimeter}{Area} = \frac{d}{\frac{}{4}d^2} = \frac{4}{d}$

$$h_f = \frac{f'}{g} \times \frac{p}{A} \times L \times V^2 = \frac{4lv^2}{d}$$

Putting $\frac{f'}{g} \times \frac{f}{2}$, where f is known as co-efficient of friction.

Equating (iv), becomes as $$h_f = \frac{4.f'}{g} . \frac{Lv^2}{d} = \frac{4f.l.v^2}{d \times 2g} \qquad \ldots..(1)$$

Equating (1) is known as Darcy-Weisbach equation. This equation is commonly used for finding loss of head due to friction in pipes.

Sometimes equation (1) is written as

$$h_f = \frac{f.l.v^2}{d \times 2g} \qquad \ldots. (2)$$

Then *f* is known as friction factor.

Co-efficient of friction (f) which is function of Reynold number is given by

$f = \frac{16}{R_e}$ for $R_e < 2000 (viscous flow)$

$= \frac{0.079}{R_e^{1/4}}$ for R_e varying from 4000 to 10^6

L = length of pipe

V = mean velocity of flow,

d = diameter of pipe.

Chezy's Equation for Loss of Head Due to Friction in Pipe

$$h_f = \frac{f \cdot l \cdot v^2}{d \times 2g} \qquad \ldots (1)$$

Where h_f = loss of head due to friction,

P = wetted perimeter of pipe,

A = area of cross-section of pipe,

L = length of pipe,

V = mean velocity of flow,

and H_f = loss of head due to friction.

Now the ratio of $\frac{A}{P}\left(\frac{Area of flow}{Perimeter(wetted)}\right)$ is called hydraulic radius and is denoted by m.

\ Hydraulic mean depth, $m = \frac{A}{P} = \frac{\frac{\pi}{4}d^2}{d} = \frac{d}{4}$

Substituting $\frac{A}{P} = m \vee \frac{P}{A} = \frac{1}{m}$ in equation (1), we get

$$h_f = \frac{f}{g} \times L \times V^2 \vee V^2 = h_f \times \frac{g}{f'} \times m \times \frac{1}{L} = \frac{g}{f'} \times m \times \frac{h_f}{L}$$

\

$$V = \sqrt{\frac{g}{f'} \times m \times \frac{h_f}{L}} = \sqrt{\frac{g}{f'}}\sqrt{m\frac{h_f}{L}} \qquad \ldots (2)$$

Let $\frac{g}{f'} = C$, where C is a constant known as Chezy's constant and $\frac{h_f}{L} = i$, where I is loss of head per unit length of pipe.

Substituting the values of $\frac{g}{f'}$ and $\frac{h_f}{L}$ in equation (2), we get

$$V = C\sqrt{mi} \qquad \ldots (3)$$

Equation (3) is known as Chezy's formula. Thus the loss of head due to friction in pipe from Chezy's formula can be obtained if the velocity of flow through pipe and also the value of C is known. The value of m for pipe is always equal to d/4.

Discharge over a Triangular Notch or Weir

The expression for the discharge over a triangular notch or weir is the same. It is derived as:

Let H = head of water above the V-notch

\ = angle of notch

Consider a horizontal strip of water of thickness 'dh' at a depth of h from the free surface of water as shown in figure below.

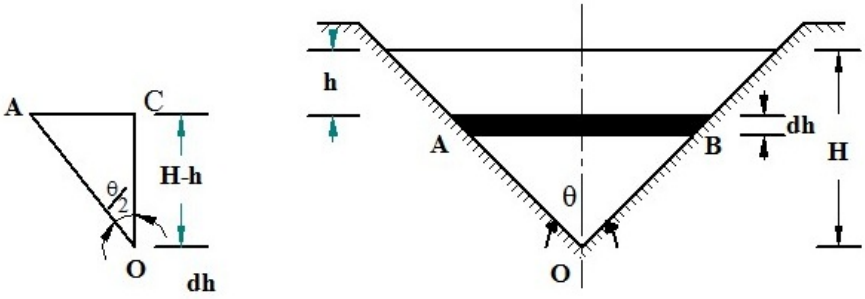


Fig. (a) Fig. (b)

The Triangular notch

From fig (b), we have

$$tan\frac{\theta}{2} = \frac{AC}{OC} = \frac{AC}{(H-h)}$$

$$AC = (H-h)tan\frac{\theta}{2}$$

Width if strip $$AB = 2AC = 2(H-h)tan\frac{\theta}{2}$$

Area of strip $$2(H-h)tan\frac{\theta}{2} \times dh$$

The theoretical velocity of water through strip $\sqrt{2gh}$

Discharge, dQ, through the strip is $dQ = C_d \times Area of strip \times Velocity^{theoretical}$

$$C_d \times 2(H-h)tan\frac{\theta}{2} \times dh \times \sqrt{2gh}$$

$$2C_d(H-h)tan\frac{\theta}{2} \times dh \times \sqrt{2gh} \times gh$$

\ Total discharge, Q is $$Q = \int_0^H 2C_d(H-h)\tan\frac{\theta}{2} \times dh \times \sqrt{2gh} \times gh$$

$$2C_d \times \tan\frac{\theta}{2} \times \sqrt{2g} \int_0^H (H-h)h^{1/2}dh$$

$$2 \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g} \int_0^H (Hh^{1/2} - h^{3/2})dh$$

$$2 \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g} \left[\frac{Hh^{3/2}}{3/2} - \frac{h^{5/2}}{5/2}\right]_0^H$$

$$2 \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g} \left[\frac{2}{3}H.H^{3/2} - \frac{2}{5}H^{5/2}\right]$$

$$2 \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g} \left[\frac{2}{3}H^{\frac{5}{2}} - \frac{2}{5}H^{\frac{5}{2}}\right]$$

$$2 \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g} \left[\frac{4}{15}H^{5/2}\right]$$

$$\frac{8}{15}C_d \times \tan\frac{\theta}{2} \times \sqrt{2g} \times H^{5/2} \qquad \text{----- (1)}$$

For a right-angled V-notch, if C_d=0.6

$$\theta = 90°, \quad \tan\frac{\theta}{2} = 1$$

Discharge $$Q = \frac{8}{15} \times 0.6 \times 1 \times \sqrt{2 \times 9.81} \times H^{5/2}$$

$$1.417H^{5/2} \qquad \text{----- (2)}$$

Experiment 1: Calibration of V-notch

Aim: to determine the coefficient of discharge cd of a given notch

Apparatus used: V-notch, Pin gauge, stop clock.

Theory:

A notch is a device used for measuring rate of flow of a liquid through a small channel or a tank. Notch can be defined as in opening in the side of a tank or a small channel in such that the liquid surface in the tank or channel is below the top edge of the opening. The sheet of water flowing through a notch is called nappe. The bottom edge of a notch over which the water flows is known as sill.

Classification of notches:

1. According to the shape of the opening
   a. Rectangular notch
   b. Triangular notch
   c. Stepped notch
2. According to the effect of the side of the nappe
   a. Notch with end contraction
   b. Notch without end contraction or suppressed notch.

   V-notch or triangular notch is a device having triangular shape opening and is preferred for measuring low discharge accurately.

Procedure:

1. Before starting the experiment note down the measuring tank dimensions and angle of V-notch.
2. Allow the water to flow up to crest level and note down their initial level of water by adjusting a pin gauge.
3. Now allow the water to flow over the V-notch by opening the discharge valve, wait up to flow should be steady state condition.
4. Start the stop clock immediately, allow the water to flow for 60sec or any fixed time interval
5. Note down the final water level in the water collecting tank and also note down the head over notch.

6. Repeat the above procedure for different head over notches by increasing discharge.
7. Calculate the co-efficient of the discharge using the formula.

Tabular Column:

Sl. No.	Head over V-notch $\times 10^{-2}$m(H_v)			Tank reading $\times 10^{-2}$m			Time in sec	Q_{act} m^3/s	Log H_v	Log Q_{act}	K from graph	Co-efficient of discharge C_d
	IR	FR	Diff.	IR	FR	Diff.						

Observations:

Angle of V-notch =

Water tank dimensions

Area =l×b= Water flow time = t=

Calculations:

1. H_V Head over V-notch
2. Tank Reading
3. Actual discharge $Qact = \frac{l \times b \times d}{t} m^3/s$

4. log H_v =
5. log Q_{act} = $(logQact - logk)/logH_v$
6. Co-efficient of discharge = $C_d = \frac{k}{\frac{8}{15}\sqrt{2gtan\frac{\theta}{2}}}$

Result: the co-efficient of discharge of a given V-notch is cd=_____

Experiment 2 : Calibration of Venturimeter

Aim: to determine the coefficient of discharge cd of a given Venturimeter.

Apparatus used: Venturimeter, U-tube manometer (H_g), stop clock, V-notch and hook gauge.

Theory:

A Venturemeter is a device used used for measuring the rate of flow of fluid flowing through a pipe. It is based on the principle of Bernoulli's theorem. It consists of three parts they are Convergent cone, throat, Divergent cone. Convergent cone has a total inclined angle of 21hI and length approximately equal to 2.7 $\left(\frac{D}{d}\right)$ the length of the throat is equal to 'd' diameter. Divergent cone has a total inclined angle of throat 6~.

Procedure:

1. Before starting the experiment note down the inlet and throat diameter and also crest level of V-notch.
2. Release the air trapped in the manometer tube by opening the air valves.
3. Using the control valve allow the water to flow through Venturimeter at the uniform rate.
4. Note down the manometer reading on both the limbs and convert into meter for water.
5. Note down the final reading of V-notch and calculate the discharge using the formula $Q_{act} = 1.417 \times Hv^{5/2} m^3/s$
6. Calculate the theoretical discharge Q_{th} using formula $Q_{th} = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh} m^3/s$
7. Finally calculate the coefficient of discharge of a Venturimeter using the formula $cd = \frac{Q_{act}}{Q_{th}}$

Observation:

1. d_1 = diameter of pipe =
2. d_2 = diameter of throat =
3. a_1 = area of pipe =
4. a_2 = area of throat =

Tabular Column:

Sl. No	Mercury Manometer reading $\times 10^{-2}$m			V-notch reading $\times 10^{-2}$m			Head over Venturimeter h=13.6×x(m of H_2O)	Q_{act} (m^3/s) $\times 10^{-3}$	Q_{th} (m^3/s) $\times 10^{-3}$	Co-efficient of discharge $c_d = \frac{Q_{act}}{Q_{th}}$
	IR (h_1)	FR (h_2)	Diff (n)	IR	FR	Diff				

Calculations:

1. Head over Venturimeter Manometer reading $x = (h_1 - h_2)$; H=13.6 × x m of H_2O
2. Head over V-notch, IR = , FR = , Diff =
3. Actual discharge = $Q_{act} = 1.417 \times H_v^{5/2} m^3/s$
4. Theoretical discharge $Q_{th} = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh} m^3/s$
5. Co-efficient of discharge = $cd = \frac{Q_{act}}{Q_{th}}$

Result:

The co-efficient of discharge of a Venturimeter is determined and tabulated and The co-efficient of discharge of a Venturimeter is found to be cd=_____

Experiment 3: Calibration of Orifice meter

Aim: To determine the co-efficient of discharge of a given Orifice meter

Apparatus used: Orifice fixed with a pipe of known diameter, Manometer, V-notch.

Theory: Orifice is a simple device to measure the flow in a pipe by reducing the flow passage in one section. The pressure difference between 2 sections is created. The measurement of pressure between 2 sections enables us to determine the discharge which is taking place in the pipe.

Procedure:

1. Before starting the experiment, note down the diameter of orifice and initial reading of V-notch.
2. Allow the water to flow through orifice and maintain the head over orifice is constant.
3. Before this, note down the initial reading of head over orifice.
4. Once the head reaches constant note down the final reading of head over V-notch is noted.
5. Finally calculate the co-efficient of discharge of orifice using the formula

$$C_d = \frac{Q_{act}}{Q_{thr}}$$

6. Repeat the experiment for different head over orifice and discharges and calculate cd.

Observation:

1. d_1 = diameter of pipe =
2. d_2 = diameter of throat =
3. length of the channel l=
4. width of channel =
5. length of pipe lp=
6. V-notch=

Tabular Column:

Sl. No	Manometer Reading (n) ×10^{-2} m			Gate Valve open	V-notch reading H_v ×10^{-2} m			h=13.6 mm of H_2O	Q_{act} m^3/s ×10^{-3}	Q_{th} m^3/s ×10^{-3}	$c_d = \frac{Q_{act}}{Q_{th}}$	From Graph		
	LC	RL	Diff.		IR	FR	Diff.					N	K	C_d

Calculations

1. Area of pipe $a_1 = \frac{{d_1}^2}{4}, a_2 = \frac{{d_2}^2}{4}$
2. Manometer reading Diff=Rl-LL
3. V-notch reading Diff=FR-IR
4. Actual discharge = $Q_{act} = 1.417 \times {H_v}^{5/2} m^3/s$
5. Theoretical discharge $= Q_{th} = \frac{a_1 a_2}{\sqrt{{a_1}^2 - {a_2}^2}} \sqrt{2gh} m^3/s$

Result: From the graph co-efficient of discharge = C_d=_____

Experiment 4: Reynolds Apparatus

Aim : To Study Laminar to Turbulent Transition for flow in a tube

Theory : Laminar flow in a tube is known to undergo transition to become turbulent with increasing values of Reynolds number. The two states of flow can be distinguished by introducing a color dye along the axis of the tube. In laminar flow, the dye remains undisturbed and moves along the tube axis. In turbulent flow, the velocity field reveals time dependent oscillations which lead to stronger mixing of the dye with the surrounding fluid.

Description

The Reynolds number (Re) is a dimensionless ratio of inertia forces to viscous forces and is used in determining the type of flow occurring: laminar or turbulent.

In most engineering text books, a Reynolds number of 2300 is usually accepted as the value at transition; that is, the value of the Reynolds number between laminar and turbulent flow regimes. The Reynolds number that exists anywhere in the transition region is called the critical Reynolds number.

The objective of this experiment is to determine the range of Reynolds numbers by Reynolds apparatus over which transition occurs.

Given the tube size (10 mm), the Reynolds number can be calculated as:

$$Re = \frac{VD_h}{\nu}$$

where,
Re = Reynolds number
V = velocity of fluid (m/s)
D_h = hydraulic diameter (m)
μ (mu) = dynamic viscosity of fluid (N.s/m^2) ν (nu) = kinematic viscosity of fluid (m^2/s) ρ (rho) = density (kg/m^3)

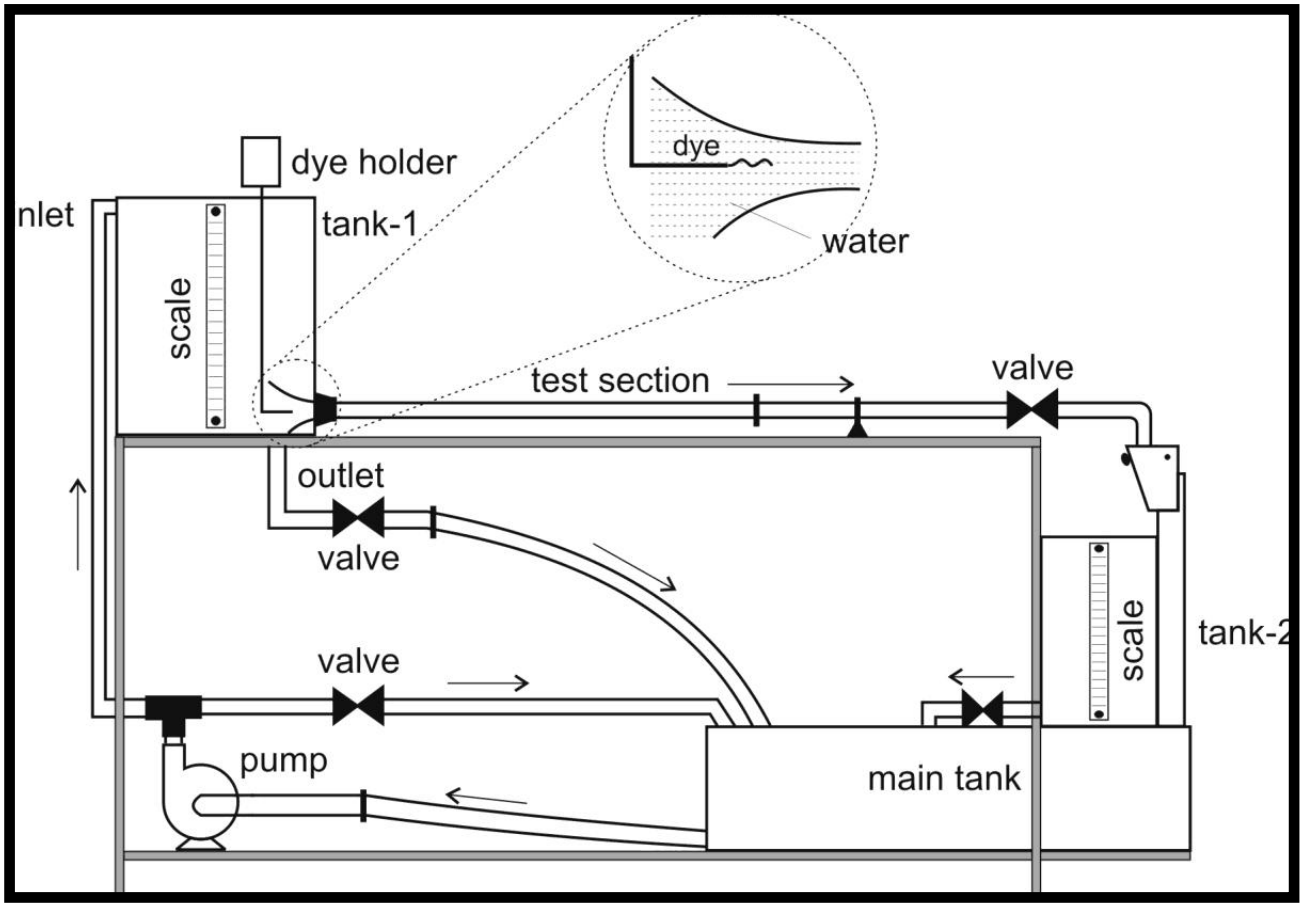
The hydraulic diameter (different than hydraulic radius) is calculated as:

$D_h = \frac{4A}{P_w}$, Wetted Perimeter P w

Apparatus Required:

The apparatus consists of a storage and supply tank, which has the provision for supplying color dye through a jet. A perspex tube is provided to visualize the flow condition within the tube. The entry of water in the perspex tube is through an elliptical bell mouth to ensure smooth flow at the entry. A regulating value is provided downstream to regulate the volumetric flow. Vary the discharge gradually to prevent flow disturbances, particularly in the transition range of Reynolds numbers.

A collecting tank is used to measure discharge of water through the tube.



The goals of the present experiment are as follows:

i. Visualize dye mixing for flow in a tube under laminar and turbulent conditions.
ii. Carefully estimate the critical Reynolds number below which flow is laminar and above which it is turbulent.

Experimental Procedure:

1. Turn on the water, and partially open the discharge valve at the base of the apparatus.
2. Open and adjust the dye injector valve to obtain a fine filament of dye in the flow down the glass tube. If the dye is dispersed in the tube reduced to water flow rate by closing the discharge valve and adjusting the supply as necessary to maintain the constant head. A laminar flow condition should be achieved in which the filament of dye passes down the complete length of the tube without disturbance.
3. Then measure the flow rate by timing the collection of a known quantity (volume) of water from discharge pipe. This will help you to determine the velocity of the water in the pipe.
4. Slowly increase the flow rate by opening the discharge valve until disturbances of the dye filament are noted. This can be regarded as the starting point of transition to turbulent flow. Increase the discharge as required to maintain constant head conditions. Do not miss to sketch the dye condition and measure the flow rate for each of your trials.
5. If necessary, increase the flow rate as described above until the disturbances increase such that the dye filament becomes rapidly diffused. Small eddies will be noted just above the point where the dye filament completely breaks down. This can be regarded as the onset of fully turbulent flow.

6.Now you should close the dye injector valve in order to finalize your experiment.

Condition	Visual Dye Condition Sketch	Time fo 300 ml of water rise in s	Flow rate $(\frac{m^3}{s})$	Velocity m/s	Re	Classification of Flow by Re
Laminar						
Laminar						
Transition						
Transition						
Turbulent						
Turbulent						
Turbulent						

Result and Discussions:

Experiment No 5: To Verify Bernoull's Theorem

Apparatus: Bernoulli's Apparatus Controlling valve at inlet and outlet, Discharge Measuring Tank, Scale, Stopwatch etc.

Formula: Total Energy = $\frac{P}{\rho g} + \frac{v^2}{2g} + z = Const$

Where $\frac{P}{\rho g}$ = Pressure Energy, $\frac{V^2}{2g}$ = Kinetic Energy, Z = Potential Energy

Theory: The Bernoulli's theorem states that the total energy of inviscid, incompressible fluid in a steady state of flow, remains constant along a stream line. Daniel Bernoulli's enunciated in 1738 that is " In any stream flowing steadily without friction, the total energy contained in a given mass is some at energy contained in a given mass is some at energy point in its path of flow."

Procedure:

1.Open the measuring tank valve fully, to keep the tank empty. Close the outlet valve.

2.Open the inlet valve and let water rise to some height 'h1' in the inlet tank. Measure this height on the piezometer.

3.Now open the outlet valve slightly and maintain height h2 < h1 to maintain the flow rate.

4. Thus adjust the outlet valve fill the water level remains constant at 'h', and also readings on each of the piezometer.

5. Check if reading is correctly written. Close the measuring tank valve. Measure the discharge, i.e. note rise in water level in 5 or 10 sec., write these and also measure and note length and breath of the tank. This completes on run. Take at least three runs by changing the discharge.

6.Note down the area of the conduit at various gauge points.

7.Open the supply valve and adjust the flow so that the water level in the inlet tanks remains constant.

8.Measure the height of water level (above an arbitrarily selected suitable plane) in different remains constant.

9.Measure the discharge of the conduit with the help of measuring tank.

10.Repeat steps 2 to 4 for two more discharges.

11.Plot graph between total energy and distance of gauge points starting from u/s side of conduit.

Observation :

Area of collecting tank = A = L x B = _____ x _____ = _____ cm^2 Difference in water level in collecting tank = Δh = _____ cm

Time required for rise of water level by 10 cm = Δt = _____ sec.

Discharge = $Q_{act} = \dfrac{\text{Volume of water}}{Time} = \dfrac{A\Delta H}{\Delta t} = _____ \dfrac{m^3}{s}$

S No	Piezometric Head $\frac{P}{w} + z$	Duct Area $a \quad cm^2$	Velocity $V = \frac{Q}{a} \frac{cm}{s}$	Velocity Head $\frac{V^2}{2g}$	Total Energy $\frac{P}{\rho g} + \frac{v^2}{2g} + z = Const$

Result:

Part B

Introduction to Wind Tunnel Experiments

Wind tunnels are devices which provides air stream under controlled conditions so that models of interest can be tested for parameters like pressure, velocity, Lift, Drag etc. Wind- tunnels are generally classified as

- Low speed tunnels
- High speed tunnels
- Specific purpose tunnels.

Objective of Wind Tunnel Experiments

The primary objective of this experiment is to familiarize the student with the measurement of static and stagnation pressures, and (indirectly) velocity, in a subsonic wind tunnel. Static taps and stagnation (Pitot) probes will be used to measure pressures on the surface of a 2-D symmetric airfoil, cambered airfoil, on circular cylinder and on a sphere. In addition, this lab demonstrates some techniques used in flow visualization, smoke visualization (in a suction type wind tunnel). Students should gain experience in observing flows and draw conclusions about the flow fields.

The Aerodynamic Problems

Pressure distribution on Airfoil Surface - When a 2-D airfoil is placed in a uniform subsonic free stream, the flow velocity near the airfoil is modified and, as evidenced by the Bernoulli equation, so is the local static pressure. The resulting chord wise pressure distribution on the surface of the airfoil may be calculated by various methods using an inviscid fluid model.

At moderate angles of attack, the flow accelerates over the upper surface of the airfoil, the surface static pressure is less than free stream over most of the chord, and the pressure coefficient (defined as $C_p = \dfrac{[p - p_\infty]}{\left(\frac{1}{2}\rho v^2\right)}$) distribution on the airfoil upper surface has mostly negative values. Normally, there is a large suction peak (large negative value of C_p) very near the leading edge on the upper surface, followed by a region of increasing static pressure (adverse pressure gradient) from there to the trailing edge. On the lower surface of the airfoil, there is a stagnation point near the leading edge, where $C_p = 1.0$, and the flow accelerates thereafter. When the two pressure coefficient distributions are plotted versus chord wise location, $\left(\dfrac{x}{c}\right)$, the area between the two curves is a measure of the normal force coefficient on the airfoil and hence of the airfoil lift coefficient.

Visualization of Flow around Bodies

Aerodynamics is a difficult science because the medium with which the aerodynamicist works (air) is not visible under normal conditions. Valuable insights into the physical features or behavior of an air flow can be achieved if the entire flow field or certain regions, e.g., streamlines (or streaklines or pathlines) could be seen by the eye or by a recording device. If the flow could be made visible by some kind of flow visualization technique, then it would be possible to observe flow phenomena which are essentially inviscid (e.g., vortical flows, flows distant from surfaces) as well as those phenomena which are dominated by the effects of viscosity (e.g., flow separation and wakes behind bodies).

Flow visualization in air may be broadly divided into surface flow visualization and off-the-surface visualization. Surface flow visualization methods include tufts, fluorescent dye, oil or special clay mixtures that are applied to the surface of a model.

Visual inspection of such tufts and coatings as a function of time, or after some time, will give valuable information on such things as the state of the boundary layer (laminar or turbulent), transition, regions of separated flow and the like. It must be remembered in such visualization that what is observed on the surface is not always indicative of what is happening away from the surface.

The second type of visualization is off the surface and involves the use of such tracers as smoke particles, oil droplets or helium-filled soap bubbles. The visualization medium must faithfully follow the flow pattern or it is not conveying the correct information. Smoke particles and oil droplets are very small and are light enough such that they will often follow the motion of the flow; soap bubbles are small and can be filled with helium to make them neutrally buoyant.

Each of these methods requires appropriate lighting and some device for recording the image, such as the human eye or a camera. If the flow-field is illuminated in a plane by appropriate masking of the light source it is possible to examine discrete sections or slices of the flow. For example, a laser light beam can be expanded into a thin sheet by passing it through a cylindrical lens. This sheet then can be used to illuminate any cross-section of an airflow that has been seeded with particles. The laser light will reflect from the particles, but dark images will be observed where there is an absence of particles, such as in the center of a vortex. A vortex core is almost void of particles since they have been spun out by the action of centrifugal force

Measuring Devices

Pressure Taps and Probes - The surface pressure distribution on an airfoil or any object under consideration will be measured by means of 30 static pressure taps. These are small holes on the surface of the model that are connected to inclined tube manometer. The pressure taps on the airfoil are located on the upper and lower surfaces in the chord-wise. In addition to qualitative observations, under certain conditions it is possible to make quantitative measurements from flow visualization data as well. For example, a measurement of the distance between streamlines in a 2-D incompressible flow provides information on velocity ratios in the flow-field direction at mid-span.

For the flow visualization experiments, no quantitative data will be taken; the emphasis is on observing the behavior of the flow and extracting conclusions from those observations.

Each student should come prepared to make notes and draw rough sketches documenting what is observed; these sketches and notes will comprise the data from the experiments.

Experiment 5: Velocity measurement using Pitot tube

Aim: To measure velocity of the flow field using Pitot tube.

Apparatus:

1. Pitot tube
2. Inclined tube manometer
3. Wind tunnel to generate wind.
4. Anemometer to measure wind speed

Procedure:-

The following procedure is adopted to measure velocity using Pitot tube.

1. The Pitot tube is fixed to the 2D traverse at the point where the measurement is desired.
2. Connect to the U-Tube manometer to the Pitot tube.
3. Switch on the wind tunnel, and adjust the rpm to desired value.
4. Maintain the speed of the tunnel for about 2 to 3 min and take the readings in the manometer.
5. Measure the speed of the wind flowing out using the anemometer at the same point.
6. Calculate the speed obtained using Pitot tube, and compare the velocities obtained using both the instruments.

Experiment 6, 7 8 and 9

Pressure distribution of circular cylinder/symmetric airfoil/cambered airfoil/sphere

AIM

To determine the pressure distribution over a circular cylinder/Sphere/Symmetric and Cambered Airfoil

APPARATUS REQUIRED

1. Cylindrical pattern/ Symmetric or Cambered Airfoil/ Sphere
2. Subsonic, wind tunnel
3. Inclined tube manometer of 30 channels
4. Control unit of wind tunnel

Procedure:

1. Mount the desired model in the test section of the wind tunnel and adjust the angle of attack.
2. Connect the pressure tapings to the inclined manometer according to the numbers provided on the tubes.
3. Adjust the reading of the inclined tube manometer to a particular height and make this height zero.
4. Connect the single channel electronic pressure scanner to the Pitot tube on the wind tunnel to record the wind speed.
5. Switch one the wind tunnel and adjust the motor rpm to the desired speed of the wind.
6. Now record the difference in the inclined tube manometer, $\Delta h = h2 - h1$.
7. Calculate the pressure at the point using the measured difference.
8. Calculate the $C_p = \dfrac{[p - p_\infty]}{\left(\frac{1}{2}\rho v^2\right)}$ value at the point.
9. Plot the Cp curve with Reynolds number.
10. Repeat the experiment at different velocity and for different angle of attack.

The above procedure can be adopted to any geometry object placed to evaluate the pressure distribution in the wind tunnel.

Calculations and Tabular Column:

Sno	Angle of Attack degrees	Wind Speed m/s	Manometer Reading for Pressure, Height in Cm																				$C_p = \frac{[p - p_\infty]}{\left(\frac{1}{2}\rho v^2\right)}$
			H1	H2	H2	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H22	

Experiment 10:- Flow Visualization using smoke rake

AIM

To find characteristics of flow field generated by objects in the flow.

Apparatus required

Airfoil (or) buff bodies like cylinder, sphere, or any automobile, Smoke generator, Laser light, paraffin wax to generate smoke.

Theory

Procedure

1. Select the object on which flow visualization is to be carried out
2. Mount the object in the test section.
3. Assemble the Laser equipment and adjust the laser sheet to the desired position.
4. Check the paraffin wax in the smoke generator bottle
5. Connect the single channel pressure measurement device to the Pitot tube to measure the air flow on the object
6. Now switch ON the heater control unit and keep out it minimum.
7. After the initial heating is done the smoke starts coming out of smoke distribution now decrease the heating in such a way that continuous smoke starts coming out of smoke rake.
8. Switch ON the motor of the tunnel.
9. Adjust the sapped to get uniform visible smoke on the airfoil model.
10. The observed the flow pattern at different orientation of models.
11. After the experiment is over switch off the heat controller of the smoke generator.
12. Allow the flow blower and fan to operate the far sometime to drive unused smoke.

CAUTIONS

1. During experimental check for blockage due to condensed oils in smoke outlet leading to distribution and drain onto sump bottle.
2. Check periodically that adequate amount of paraffin is available in the over neat bottle.
3. Never switch ON the heater for long time of the smoke generator unit.