Laboratory Manual

FLUID MECHANICS LAB

for

B. Tech.
Mechanical Engineering

Department of Mechanical Engineering

Rukmani & Sons

Brij Bhooshan Education Web Portal
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Prepared by

A team of
Rukmani & Sons

E-mail: enquiry@brijrbedu.org
Website: http://www.brijrbedu.org

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LABORATORY OBJECTIVE

Fluid Mechanics define the nature of a fluid. It shows where fluid mechanics concepts are common with those of solid mechanics and indicate some fundamental areas of difference. It introduce viscosity and show what are Newtonian and non-Newtonian fluids and also define the appropriate physical properties and show how these allow differentiation between solids and fluids as well as between liquids and gases.

By Fluid Mechanics, Students will be able to do the following:

- Read and follow directions for laboratory experiments.
- Operate fluid flow equipment and instrumentation.
- Collect and analyze data using fluid mechanics principles and experimentation methods.
- Prepare reports following accepted writing and graphical techniques.
- Perform exercises in small teams.
- Demonstrate principles discussed in Fluid Mechanics lecture course.
- Demonstrate appropriate work habits consistent with industry standards.

ABOUT THE LABORATORY

The Fluid mechanics Laboratory deals with the characteristics of Fluid in behalf of different Apparatus, behavior of the fluid.

This laboratory contains the following setups and equipments:

1. Meta centric height apparatus
2. Impact of jet apparatus
3. Orifice meter apparatus
4. Reynolds's number apparatus
5. Mouth piece apparatus
6. Pipe friction apparatus
7. Pitot Static tube apparatus
8. Losses in pipe apparatus

GUIDELINES FOR TEACHERS/TECHNICAL ASSISTANTS

1. Know the laboratory: The teacher is expected to understand the layout of laboratory, specifications of equipments/instruments/materials, procedure of experiments, method of working in groups, planning time etc.
2. Ensure that required equipments are in working condition before start of experiment and also keep the operating or instruction/user manuals of equipments/instruments and this laboratory manual available.
3. On the first day of the lab, inform the students about the importance of subject/laboratory, various equipments/instruments that will be used in the lab etc. Also instruct them how to make the practical record file for this lab.
4. Explain the theoretical concepts, relevant to the experiment, to the students before start of each practical.
5. Demonstrate the experiment(s) clearly to the students group-wise.
6. Instruct the students to perform the practical. While taking reading/observation, each student must get a chance to perform or observe the experiment.
7. If the experimental setup has variations in the specifications of the equipment, the teachers are advised to make the necessary changes.
8. Teacher shall assess the performance of students by observation or by asking viva related questions to the students to tap their achievements regarding related knowledge/skills so that students can prepare accordingly.
9. The teacher must check carefully and sign the practical record file of the students periodically.
10. Teacher shall ensure that the industrial/site/plant visits recommended as per the syllabus of laboratory are covered.
11. Teacher should ensure that the respective skills and competencies are developed in the students after the completion of the practical exercise.
12. Teacher may provide additional knowledge and skills to the students albeit not covered in the manual but are expected from students by the industries.
13. Teacher may suggest the students to refer additional related literature of the technical papers, reference books, seminar proceedings etc.
14. Teacher can organize group discussions/brain storming sessions/seminars to facilitate the exchange of practical knowledge amongst the students.

GENERAL PRECAUTIONS AND SAFETY PROCEDURES

1. Teacher/technical assistant must ensure that all the electrical equipments/ instruments are used and periodically performance tested as per manufacturer's recommendations (permissible electrical and ambient temperature ratings).
2. Before use, the electrical equipment, extension cords, power tools etc. must be inspected for any damage (worn insulation, bent/missing pins, etc.). Any equipment found to be damaged or otherwise unsafe must be removed from service.
3. The mains plug of equipments must only be inserted in a socket outlet provided with a protective earth contact.
4. **WARNING**: The protective earth connection inside or outside the equipments/instruments must NEVER be interrupted or tampered. **IT CAN MAKE THE EQUIPMENT DANGEROUS**.
5. If an instrument shows visible damage or fails to perform the intended measurements, it is likely that the protection has been impaired. In such case the instrument must be made inoperative and the necessary repairs should be carried out.
6. Extension cords or power strips must not be plugged into one another so as to increase the overall reach.
7. Report all problems with building electrical systems to the teacher/technical assistant/maintenance for corrective action.
8. In case of any electrical hazard/fire reach out for the nearest fire-extinguisher or sand and use it for putting out the fire. Report immediately to the teacher/ technical assistant nearby.
9. For reasons of safety, every student must come to the laboratory in shoes (covering the whole feet).
10. Avoid wearing garments with loose hanging parts. The students should also ensure that floor around the equipment/machine is clear and dry (not oily) to avoid slipping. Please report immediately to the lab staff on seeing any coolant/oil spillage.
11. The student should take the permission and guidance of the lab staff/teacher before operating any equipment/machine. Unauthorized usage of any machine without prior guidance may lead to fatal accidents and injury.
12. The student will not lean on the equipment/machine or take any kind of support of the machine at any point of time.

INSTRUCTIONS FOR STUDENTS

1. Listen carefully to the lecture and instructions given by the teacher about importance of subject/laboratory, curriculum structure, skills to be developed, information about equipment and instruments, procedure, method of continuous assessment, tentative plan of work in laboratory and total amount of work to be done in the semester/session.
2. Read and understand the theory of each experiment to be performed, before coming to the laboratory.
3. Understand the purpose of experiment and its practical implications. Observe carefully the demonstration of the experiment. When you perform it, organize the work in your group and make a record of all observations.
4. In case of absence, the student must perform the experiment(s) on the next turn or in his/her spare time with permission from the teacher/lab assistant.
5. Student should not hesitate to ask any difficulty faced during conduct of practical/exercise.
6. The student shall study all the questions given in the laboratory manual or asked by the teacher and know the answers to these questions properly.
7. The required instruments/tools will be issued from the laboratory store. They must be returned to the store on the same day at the end of lab hours.
8. Laboratory reports (practical file) should be submitted in a bound file or on A4 size sheets, properly filed, on the next turn completed in all respects i.e. with experiment(s) written, graphs attached (if applicable) and entries made in the list of contents of the file and get them checked from your laboratory teacher. Laboratory reports have associated grades/marks.
9. Student should not bring any food or drink item to the laboratory.
10. Student should develop habit of group discussion related to the experiments/exercises enabling exchange of knowledge/skills.
11. Student shall gain knowledge and develop required practical skills and competencies as expected by the industries.
12. Student shall develop the habit of evolving more ideas, innovations, skills etc. than included in the scope of the manual.
13. Student shall refer technical magazines, proceedings of the seminars; refer websites related to the scope of the subjects and update their knowledge and practical skills.

EXPERIMENT – 1

OBJECTIVE:

To determine the metacentric height of the given ship model.

APPARATUS USED:

1. The arrangement in which a ship model is to float in the small tank (850 × 850 × 310) mm.
2. Jockey weight = 500gm., 250gm. And 100gm. Are provided.
3. Graduated arc and pendulum arrangement is provided to measure the angle of tilt.
4. A cross bar is provided in the ship model to place the load at desired distance (X).

THEORY:

The stability of a body such as ship, which floats on the surface of a liquid, is of having the great importance. Whether the equilibrium is stable or unstable is determine by the height of its center of gravity.

The weight of the pontoon acts vertically downwards through its center of gravity, G and this is balanced by an equal and opposite buoyant force acting upwards through the center of buoyancy, 'B' which lies at the center of gravity of liquid displayed by the pontoon.

Corresponding to small angular displacement 'θ' from the equilibrium position, due to the displacement 'X' of the jockey weight, the center of gravity of the liquid displaced by the pontoon shifts from 'B' to 'B1' and the vertical line of action of the buoyant force intersects the extension of the line BG in M the metacenter.

The equal and opposite forces through G and B1 exert a couple in the pontoon, and provide the M lies above G. This couple acts in the sense of restoring the pontoon to even keel, the pontoon is stable. If however, the metacenter M lies below, the center of gravity G, the sense of couple is to increase the angular displacement and the pontoon is stable. The special case occurs when M&G coincides.
Then the distance is given by

$$GM = w.\ X/W.\tan\theta$$

OBSERVATIONS:

1. Weight of the ship model = Ws = 8.840 kg
2. Total weight of the ship, W = (Ws + w) kg
3. Angle of tilt = θ
4. Weight (a) 250 gm each hanging weight, (b) 100 gm & 250 gms standing
5. Distance of stand weights from the center = 145mm, 85mm, 45mm.

OBSERVATIONS TABLE:

S.No.	Load in kg (LH)	Angle (θ)	Distance *X* (cm)	Load in kg (RH)	Angle (θ)
1					
2					
3					
4					
5					

CALCULATIONS:

Then the distance is given by

$$GM = w.\ X/W.\tan\theta$$

RESULT:

The metacentric height of the given ship model is ……………………………….

PRECAUTIONS:

1. Reading should be noted carefully.
2. There should be no mechanical vibration near the apparatus.

EXPERIMENT – 2

OBJECTIVE:

To verify momentum theorem experimentally.

THEORY:

Whenever the velocity of a stream is changed either in magnitude or in direction, a force is required to bring this change. Thus the momentum theorem states that the sum of all the externally applied forces on a given control volume is equal to the rate of change of momentum brought in the direction of forces.

$$\Sigma F = \rho Q\,(U_2 - U_1)$$

where ΣF is the sum of all forces acting in one direction. By Newton's third law of motion, an equal and opposite force is applied by the fluid on the body, which brings the change in momentum. Since the jet of the fluid turns by right angle when it is striking on a flat plate the final velocity U_2 will be zero.
Hence

$$\Sigma F = \rho Q U_1$$

PROCEDURE:

1. Mark the position of vertical lever and horizontal arm when there is no weight on the pan.
2. Open the inlet valve so that the jet of water strikes the flat plate at its center the lever is deflected to one side.
3. Put a weight 'W' on the pan so as to bring the lever in its original position as marked in step 1.
4. Measure the discharge Q by volumetric methods.
5. Repeat the same step 2 & 4 for various other discharges.

OBSERVATION:

Diameter of nozzle	= ………………m
Area of nozzle	= ………………m^2
Area of measuring tank	= ………………m^2
Horizontal length of lever (l_1)	= ………………mm
Vertical length of lever (l_2)	= ………………mm

OBSERVATION TABLE:

S.No.	Discharge Q (m^3/sec.)	Weight of the pan (w) in Newton	Eq. due to jet (F_1)	Force due to jet (F_1)	% age error
1					
2					
3					
4					
5					

CALCULATION:

Discharge, Q = area of measuring tank × raised height/time taken in sec.
The moment of W and F about the lever arm hinged at R yields

$$WL_1 = WL_2$$

$$F_1 = L_1.W/L_2$$

Theoretical force imparted by the jet on the flat plate is

$$F = \rho.Q.U$$

$$F = (W/g) \times Q \times U$$

$$F = W.\ Q^2/g.a \qquad (U = Q/a)$$

Percentage error is

$$(F - F_1)/F \times 100\%$$

RESULT:

Plot F vs. F1. It should be a straight line inclined at 45 deg. to the X-axis. Thus it proves the theorem.

PRECAUTIONS:

1. The discharge should remain constant in one set of reading.
2. The jet issued from the nozzle should be solid and no water should spray in the atmosphere, so that the whole mass of fluid impinges on the jet plate.
3. The hinges R&S should work smoothly.

EXPERIMENT – 3

OBJECTIVE:

To determine the coefficient of discharge through orifice meter.

THEORY:

Orifice meter, also known as orifice plate meter, a device is used to measure the flow rate in any closed pipeline. It is different from the Venturimeter in the sense that is provides sudden change in flow conditions instead of smooth transition provided by the Venturimeter as the liquid passes through orifice meter, a lot of eddies are formed and there is loss energy due to which the measured value of discharge, 'Q' is less and given by

$$Q = a_1 a_2 \frac{\sqrt{2gH}}{\sqrt{a_1^2 - a_2^2}}$$

where

a_1 = area cross section of an up stream section (dia. of pipe = 28mm.)
a_2 = area of cross section of orifice meter (dia. of orifice = 12mm.)
g = acceleration due to gravity
h = head difference between pipe and orifice

$$H = [(S_2/S_1) - 1] \times h$$

where

S_1 = Sp. Gravity of water.
S_2 = Sp. Gravity of Hg.

OBSERVATION:

Dia of orifice = 12mm.
Area of measuring tank = (0.38×0.31) m^2

OBSERVATION TABLE:

S.No.	H_1 (cm.)	H_2 (cm.)	$H = h_1 - h_2$ (cm.)	Difference $H = [(S_2/S_1) - 1] \times h$	Time Required for 100 mm rise in water level
1.					
2.					
3.					

CALCULATION:

Theoretical Discharge (Q_{th})

$$Q_{\text{th}} = a_1 a_2 \frac{\sqrt{2gH}}{\sqrt{a_1^2 - a_2^2}}$$

Actual Discharge (Q_{act})

$$Q_{\text{act}} = \frac{\text{Area of measuring tank } \times 0.1}{\text{Time required in seconds}}$$

Coefficient of discharge

$$= Q_{act}/Q_{th}$$

RESULT:

The coefficient of discharge of orifice-meter is ....

PRECAUTION:

1. There should be no air bubble entrapped while taking reading of level in piezometric tube.
2. Check that the top level of measuring liquid is same in the limbs of the different manometer.

EXPERIMENT – 4

OBJECTIVE:

To studies the transition from laminar to turbulent flow and to determine the lower critical Reynold's number.

APPARATUS:

A constant headwater tank, a transparent pipe, a control valve at the down stream end, a dye injection system and a suitable dye e.g. potassium paramagnet solutions.

THEORY:

Start the experimental observations by opening control by the control valve slightly and injecting little dye streaks appear straight.

Slight increase of flow rate makes no significant difference to the streak from but after a certain stage, the dye streaks appear wavy and disturbed. Further opening of the valve results in complete disruption of the dye in the fluid. This is the process of change over from laminar to turbulent flow by changing U or Re since de and H are kept constant.

Under carefully controlled conditions the laminar flow can be maintained up to Re = 4000 or so but under normal circumstances, the transition occurs between Re = 2000 to 3000 in the process of changing from laminar to turbulent. Below 2000 laminar flow persists whereas above 3000 laminar flow may change to turbulent flow in the presence of the slightest disturbance. The Reynold's up to which laminar flow may; be maintained is said to be the upper critical Reynold's number.

For a round pipe of given diameter 'd' and the fluid properties ρ and H, the corresponding velocity is said to be the upper critical velocity.

Characteristics of Laminar And Turbulent Flow:

When the velocity is gradually reduced to change the nature of flow from turbulent to laminar the Reynold's number is always required to be reduced to 2000. The Reynold's no. to which the flow should be reduced to change from turbulent to laminar flow is called the lower critical Reynold's number and the corresponding velocity of flow for a given pipe and fluid is called the lower critical velocity.

In order to appreciate the total change in the nature of flow, we install a differential pressure manometer between two stations 1 & 2 located '1m' apart and record the pressure drop δP as the velocity or the Reynold's number increases, the plot appears as in the fig. In laminar flow, the pressure drop is proportional to the velocity where as in turbulent flow it is a function of square of velocity. This is explained by the increased mixing and steeper velocity profile near the wall in turbulent flow.

It may also be noticed that a typical laminar velocity profile is parabolic where as a typical velocity profile is near uniform power profile.

$$Re = 4Q/\pi D\mu$$

where

Q = Discharge
D = inner diameter of pipe (17.76)
μ = Kinematics viscosity (10^{-6})
upto Re = 2000, the flow in the pipe is laminar & beyond
Re = 3000, the flow is turbulent & for values between the 2000 to 3000 the flow is unpredictable

OBSERVATION:

Diameter of the glass tube (I/D) = 17.76 mm.
Kinematics viscosity of water = 10^{-6} m^2/sec.

OBSERVATION TABLE:

S.No.	Volume in (m^3/sec.)	Time required in sec. (t)	Discharge (liter/sec)	Discharge (m^3/sec)
1				
2				
3				

CALCULATIONS:

$$Re = 4Q/\pi D\mu$$

where

Q = Discharge
D = inner diameter of pipe (17.76)

μ = Kinematics viscosity (10^{-6})

RESULTS:

PRECAUTIONS:

1. Do not forget to remove any entrapped air in the apparatus before starting the measurement.
2. Increase in velocity of flow should be in the stages.
3. There should be no mechanical vibration near apparatus.

EXPERIMENT – 5

OBJECTIVE:

To study the velocity distribution in a pipe and also to compute the discharge by integrating the velocity profile.

THEORY:

The flow of a fluid is said to be laminar if the flow is characterized by the fluid particles staying in laminate i.e. thin sheets. Each laminate may be considered to be a stream surface. The shape of laminar depends upon the shape of the boundaries of the passage. For example, if the flow takes place between two parallel plates, the lamina must be plane sheets parallel to each other (which are as shown in fig. 1).

Laminar Flow through a Round Pipe:

Consider a laminar flow through a horizontal round pope as shown in fig.2. This is also referred as HAGEN – POISEULLIE flow. The proceeds in cylindrical laminar as shown in Fig. 1. The equilibrium of a cylinder of a radius 'r' contained in a lamina of radius 'r + δr' is considered. For equilibrium the net pressure force on its periphery due to the presence of cylindrical lamina over it.

$$p\pi r^2 - (p + \delta p)\, \pi r^2 \;\; = \tau .\, 2\pi r .\, \delta x$$

$$\delta p \pi r^2 \; = \tau .\, 2\pi r .\, \delta x$$

Therefore

$$\tau = -\frac{dp}{dx}.\frac{r}{2} \qquad [1]$$

If the laminar flow in a pipe is fully developed i.e. the velocity profile does not change in the longitudinal direction, the velocity 'u' varies only with 'r' and the pressure 'p' remains constant over the cross section.
Under such conditions, the longitudinal pressure gradient dp/dx remains constant Hence 'τ' is proportional to 'r'.

Which shows that the shear stresses varies linearly along the radius of the pipe. The maximum shear stress τ_{max} occurs at the pipe wall i.e. at r = R.

$$\tau_{max} = \frac{dp}{dx}.\frac{R}{2} \qquad [2]$$

The velocity distribution in the pope may be obtained by invoking the relationship

$$\tau = \mu\, du/dy$$

where y is measured from the wall

Since, $y = R - r$

and $dy = -dr$

It follows that,

$$\tau = -\mu\, du/dy \qquad [3]$$

Substituting this relationship in the equation (1)

$$\frac{dy}{dr} = \frac{1}{2}\mu\left(\frac{dp}{dx}\right)r$$

$$u = \frac{1}{4}\mu\left(\frac{dp}{dx}\right)r^2 + k$$

On integration,

At $r = R$, $u = 0$

$$k = -\frac{1}{4}\mu\left(\frac{dp}{dx}\right)R^2$$

$$u = -\frac{1}{4}\mu\left(\frac{dp}{dx}\right)\left(R^2 - r^2\right)$$

$$u = -\frac{1}{4}\mu\left(\frac{dp}{dx}\right)R^2\left(1 - \frac{r^2}{R^2}\right) \qquad [4]$$

The above equation is of parabola.

It shows that the velocity profile in a fully developed laminar flow must be a parabolic or revolution.

At r = 0, the centerline of the pipe,

$$u_{max} = -\frac{1}{4}\mu\left(\frac{dp}{dx}\right)R^2 \qquad [5]$$

Then $u = u_{max}\left(1 - \frac{r^2}{R^2}\right)$

Total discharge through the pipe Q,

$$Q = \int dq = \int_0^R 2\pi r\, u_{max}\left(1 - \frac{r^2}{R^2}\right) dr$$

$$Q = 2\pi u_{max} R^2/4$$

Substituting the value of u_{max} form equation (5)

$$Q = -\frac{\pi}{128}\mu D^4\left(\frac{dp}{dx}\right)$$

The above equation is known as HAGEN-POISEUILLE equation for laminar flow through the pipe.

RESULT:

In this way we can able to draw the velocity distribution in the pipe as well as we can calculate the discharge.

EXPERIMENT – 6

OBJECTIVE:

To study the variation of friction factor 'f' for turbulent flow in smooth and rough commercial pipes.

THEORY:

As we know that the loss of head due to friction may be calculated with the help of Darchy Weishbach formula, which is given as below.

$$h_f = \frac{fLV^2}{2gD}$$

where 'f' is known as friction factor or coefficient of friction, which is a dimensionless quantity. It may be noted that the head loss due to friction is also expressed in terms of the velocity head ($V^2/2g$) corresponding to the mean velocity. Further the observation show that the coefficient 'f' is not constant but its value depends on the roughness condition of the pipe surface and the Reynold's number of the flow. As such in order to determine the loss of head due to friction correctly, it is essential to estimate the value of friction factor 'f' correctly.

A number of empirical formula have been suggested for the friction coefficient 'f' which has been experimentally found to depend upon the flow Reynolds number and the relative roughness of the pipe surface. The coefficient of friction decreases with growth in Reynolds number, however beyond a certain value of relative roughness; it becomes independent of Reynolds number. For a constant value of Reynolds number, the friction coefficient goes on increasing with relative roughness. For a given roughness the variation of 'f' with Reynolds number has been prescribed by the following relations.

1. Friction Factor (4f) = 64 / Re
   This follows directly from the following two relations.
   (a) For laminar viscous flow through a pipe

$$h_f = \frac{32\mu VL}{wd^2} = \frac{32\mu VL}{\rho g d^2}$$

   (b) If Darchy's equation is thought to hold viscous flow, then

$$h_f = \frac{fLV^2}{2gD}$$

From (a) and (b) we get,

$$4f = 64/\mathrm{Re}$$

Thus Darchy's equation is valid for both laminar and turbulent flow, the difference lies in the value of friction coefficient.

2. Blasius equation for $20 \times 10^3 < \mathrm{Re} < 80 \times 10^3$

$$4f = \frac{0.3164}{\mathrm{Re}^{0.25}}$$

3. Nikuradse equation for $4 \times 10^3 < \mathrm{Re} < 3.2 \times 10^6$

$$4f = 0.0032 + \frac{0.221}{\mathrm{Re}^{0.237}}$$

4. Schiller equation for $2 \times 10^4 < \mathrm{Re} < 2 \times 10^6$

$$4f = 0.005 + \frac{0.396}{\mathrm{Re}^{0.3}}$$

The general graphical relationship between 'f' and 'Re' takes the form as depicted in the fig. Portion AB represents laminar flow, portion BC represents the transitional zone and portion CD represents the turbulent flow. The point B & C indicate the lower & higher critical velocity respectively.

EXPERIMENT – 7

OBJECTIVE:

To determine the loss coefficients for pipe fittings.

TEST SETUP:

1. Test setup of pipe fitting apparatus.
2. Stop Watch
3. Accessories

THEORY:

When liquid flow through the pipes, they have to overcome the friction offered by the rough projections of the inner walls of the pipe material. Resistance is also offered by the pipe fittings which dissipate the hydraulic energy; these resistances are also called as frictional resistance and are responsible for the loss of head of water.

Variable Velocity Head Loss:

The head loss due to variable velocity takes place whenever the value of flow velocity changes as a consequences of the changes in the cross section available for flow due to pipe entrance, sudden enlargement, sudden contraction and pipe fittings like elbows, valves, bends, tees, etc.

(a) Loss of head due to sudden enlargement, $h_e = (V_1 - V_2)^2/2g$
(b) Loss of head due to sudden contraction, $h_e = 0.5\ V^2/2g$
(c) Head loss due to bends, $h_e = 0.25\ V^2/2g$
(d) Head loss due to elbows, $h_e = 0.25\ V^2/2g$

EXPERIMENTAL SETUP:

1. Sump Tank -- 1220 × 410 × 410
2. Measuring Tank -- 410 × 330 × 410
3. Basic Piping
4. Pipe Fittings
   (a) Sudden enlargement
   (b) Sudden contraction
   (c) Pipe Band

(d) Pipe elbow

5. Flow Control Valve
6. Differential Manometer

OBSERVATION:

(a) Dia. of pipe = 0.03m
(b) Dia. of enlargement = 0.05m
(c) Dia. of Contraction = 0.03m
(d) Dia. of Bend = 0.27m
(e) Dia. of elbow = 0.03m
(f) Area of measuring tank = 0.41 × 0.33

OBSERVATION TABLE:

(A) **For Sudden Enlargement**

S.No.	Manometer Reading (H_1)	Manometer Reading (H_2)	Difference ($H_1 - H_2$)	Time taken for 100 mm rise in water level

(B) **For Sudden Contraction**

S.No.	Manometer Reading (H_1)	Manometer Reading (H_2)	Difference ($H_1 - H_2$)	Time taken for 100 mm rise in water level

(C) For Bend

S.No.	Manometer Reading (H_1)	Manometer Reading (H_2)	Difference ($H_1 - H_2$)	Time taken for 100 mm rise in water level

(D) For Elbow

S.No.	Manometer Reading (H_1)	Manometer Reading (H_2)	Difference ($H_1 - H_2$)	Time taken for 100 mm rise in water level

CALCULATION:

Head lost in meters of water (1m of Hg = 13.6m of water)

Velocity (V) in m/sec., V = Q/A = discharge / area of pipe fittings (in m2)

Q = area of measuring tank × 0.1 / time taken for 100 mm rise of water level

(a) Loss of head due to sudden enlargement, $h_e = (V_1 - V_2)^2/2g$

(b) Loss of head due to sudden contraction, $h_e = 0.5\ V^2/2g$

(c) Head loss due to bends, $h_e = 0.25\ V^2/2g$

(d) Head loss due to elbows, $h_e = 0.25\ V^2/2g$

RESULT TABLE:

S.No.	Head loss in friction (h_f)	Discharge in (m^3/sec.)	Head loss in friction (h_f)	Velocity in (m/sec.)	Average (H)

PRECAUTION:

1. Take care that there is no air bubble entrapped in apparatus when noting manometer reading.
2. There should be no leakage from any of the pipe fittings.

EXPERIMENT – 8

OBJECTIVE:

To Study the flow behavior in a pipe bend and to calibrate pipe bend for discharge measurement.

THEORY:

In many problems of fluid mechanics, there occurs a change in velocity of a steadily moving fluid; this change may be in magnitude and direction of both. Magnitude of force required to affect this change can be calculated by the use of momentum principle which states that.

"The time rate of change of momentum is proportional to the impressed force and takes place in the direction in which force acts."

Momentum is the product of the mass and the velocity of the body and represents the energy of motion stored in a moving body.

$$d/dt\,(mV) = m.dV/dt + V.dm/dt$$

For a constant fluid mass, $dm = 0$ and therefore,

$$F = m.dV/dt$$

or

$$F.dt = mdV$$

The quantity F.dt (the product of force and the time increment during which it acts) represents the impulse of applied force, while the quantity m.dv represents the change in momentum. The above equation is known as the Impulse – momentum theorem which may be stated as.

"The impulse due to force acting on a fluid mass in a small interval of time is equal to change in the momentum of the fluid mass."

Forces Exerted On Or By The Pipe Bends:

Consider steady flow of fluid through a diverging stream tube lying entirely in the X-Y plane. Flow can be assumed steady, uniform and normal to the inlet and outlet areas. The fluid mass has average velocity, V1 and density at entrance ρ2. Under the effect of the external forces on the stream, the mass of the fluid in the region abcd shifts to a new position a'b'c'd' after a short interval of time dt.

Because of gradual increase in flow area in the direction of flow, velocity of fluid mass and hence the momentum is gradually reduced. Since the area a'b'c'd' is common to both the region abcd and a'b'c'd', it will not experience any momentum change. Evidently then the momentum changes of the fluid masses in the section abb'a' and cc'd'd have to be considered.

Invoking the principle of mass conservation, the following continuity equation is applied:

Fluid mass within the region abb'a' = fluid mass within the region cc'd'd

$$\rho_1 A_1 ds_1 = \rho_2 A_2 ds_2 \qquad [1]$$

So the momentum of fluid mass contained in the region abb'a'

$$= (\rho_1 A_1 ds_1) V_1 = (\rho_1 A_1 V_1 dt) V_1$$

And the momentum of fluid mass contained in the region cc'd'd

$$= (\rho_2 A_2 ds_2) V2 = (\rho_2 A_2 V_2 dt) V_2$$

Change in momentum

$$= (\rho_2 A_2 V_2 dt) V_2 - (\rho_1 A_1 V_1 dt) V_1$$

For steady flow $\rho_1 = \rho_2 = \rho$ and from continuity equation

$$A_1 V_1 = A_2 V_2 = Q \text{ (discharge)}$$

So, Change in momentum

$$= \rho Q (V_2 - V_1) dt \qquad [2]$$

By impulse – momentum principle,

$$F.dt = \rho Q (V_2 - V_1) dt$$

$$F = \rho Q (V_2 - V_1) dt$$

This is the basic momentum flux equation. The quantity ρQ is the mass per second and is called the mass flux.

Force F and the velocity vectors V_1, V_2 are all vector quantities and can be resolve into components in the directions of co-ordinates X and Y. If θ_1 and θ_2 are the prescribe inclination with horizontal of the centerline of the pipe at ab and ed, then components of V_1 and V_2 along X-axis are:

$$V_1 \cos \theta_1 \text{ and } V_2 \cos \theta_2$$

Components of V_1 and V_2 along Y – axis are:

$$V_1 \sin \theta_1 \text{ and } V_2 \sin \theta_2$$

So the components of force along X-axis and Y-axis are:

$$F_x = \rho Q\,(V_2 \cos\theta_2 - V_1 \cos\theta_1)$$
$$F_y = \rho Q\,(V_2 \sin\theta_2 - V_1 \sin\theta_1) \qquad [3]$$

Equation (3) represents the force components exerted by the pipe bends on the fluid on the pipe bend, invoking Newton's third law of motion, the fluid mass would exert the same force on the pipe bent but in the opposite direction, therefore, the force components exerted by the fluid on the pipe bend are:

$$F_x = \rho Q\,(V_1 \cos\theta_1 - V_2 \cos\theta_2)$$
$$F_y = \rho Q\,(V_1 \sin\theta_1 - V_2 \sin\theta_2) \qquad [5]$$

The magnitude of resultant force exerted by the fluid is

$$F = \sqrt{F_x^2 + F_y^2}$$

and the direction of the force with X-axis is

$$\theta = \tan^{-1}(F_y/F_x)$$

The static pressure forces acting over the inlet and outlet sections must supplement the dynamic force computed from the above equation:

$$F_x = \rho Q\,(V_1 \cos\theta_1 - V_2 \cos\theta_2) + p_1 A_1 \cos\theta_1 - p_2 A_2 \cos\theta_2$$
$$F_y = \rho Q\,(V_1 \sin\theta_1 - V_2 \sin\theta_2) + p_1 A_1 \sin\theta_1 - p_2 A_2 \sin\theta_2 \qquad [3]$$

RESULT:

In this way we can study the effects of flowing fluids on the pipe bends and similarly we can calculate the discharge from the continuity equation.

EXPERIMENT – 9

OBJECTIVE:

To Study the laminar boundary layer velocity profile and determine the boundary layer thickness and displacement thickness. Also to determine the exponent in the power law of velocity distribution.

THEORY:

For defining the boundary layer (i.e. laminar and turbulent boundary layer) consider the following liquid. Having free stream velocity (U), over a smooth thin plate which is placed parallel to the direction of free stream which is as shown in fig.

The velocity of fluid on the surface of the plate should be equal to velocity of the plate. But plate if stationary and hence velocity of fluid on the surface of the plate is zero. But at a distance away from the plate, the fluid is having certain velocity gradient develops shear resistance, which retards the fluid, thus the fluid either a uniform free stream velocity (U) is retreated in the vicinity of the solid surface of plate in the boundary layer region begins at the sharp leading edge. At subsequent points downstream the leading edge the boundary layer increases because the retarded fluid is further retarded. In this way there is a formation of boundary layer and that is called as laminar boundary layer. This is shown by the portion AE in the fig. the length of the plate from the leading edge up to which laminar boundary layer exists is called laminar zone, the Reynolds number for which is given by

$$\text{Re} = \frac{ux}{\nu} = 5 \times 10^5 \text{ (for boundary layer)}$$

where,

x = distance from leading edge
u = free steam velocity
ν = kinematics viscosity

Boundary Layer Thickness ('δ'):

The distance 'y' where 'u' becomes 99% of 'U'. where u is velocity at a particular instant i.e. when the difference between 'u' and 'U' remains 1%. This is only to approximate the region of non-uniform flow. This thickness is however, devoid of any physical interpretation and is not commonly used in engineering. Therefore, the means of expressing the growth of boundary layer. These are also recognized the boundary layer thickness parameters.

Displacement Thickness (δ*):

The distance 'Y' by shih the external free streams is effectively displaced due to the formation of the boundary layer.
If a free stream of velocity 'U' is effectively displaced by δ the loss of flow over the displacement equals

$$= \delta^* u\rho \text{ per unit time.} \quad [1]$$

Loss of flow actually affected by the profile i.e. the elementary hatched area at distance 'Y'

$$\delta L = \rho\ (U - u)\ dy$$

Total loss of flow

$$L = \int_0^\delta \rho(U - u)\ dy \text{ per unit time} \quad [2]$$

As represented by the shade area, from equation (1) and (2)

$$U\rho\delta^* = \int_0^\delta \rho(U - u)\ dy \text{ per unit time}$$

and for incompressible flow displacement thickness becomes,

$$\delta^* = \int_0^\delta \left(1 - \frac{u}{U}\right) dy$$

Displacement thickness in terms of boundary layer thickness can be given as.

$\delta^* \equiv \delta/3$ for laminar profile
$\delta^* \equiv \delta/8$ for turbulent profile

Based upon considerable experimental evidence, Prandtl suggest that a single parametric relation of the form could approximate the mean velocity distribution for turbulent boundary layer flow:

$$u/U = (y/\delta)^{1/7}$$

This is known as one seventh power law.

This relation tends itself of its readily to the mathematical analysis because of its extreme simplicity. However, the relation predicts in finite shear at the bounding surface as is evident from the infinite velocity gradient at the surface.

$$\left[\frac{du}{dy}\right]_{y=0} = \left|\frac{1}{7}\left(\frac{u}{\delta^{1/7}}\right)\left(\frac{1}{y^{6/7}}\right)\right|_{y=0\to\infty}$$

The difficulty is circumvented by considering the velocity in the viscous sub-layers to be linear and tangential to the seventh root profile at the point where laminar merges with the turbulent part of boundary layer.