Bapuji Educational Association®

Bapuji Institute of Engineering and Technology,

Davangere-577 004

Department of Chemical Engineering

MOMENTUM TRANSFER
LABORATORY MANUAL
(18CHL37)

For students of III semester B.E. Chemical Engineering

of

Visvesvaraya Technological University, Belgaum

Prepared By

Department of Chemical Engineering

INSTITUTE VISION, MISSION AND QUALITY POLICIES

VISION

"To be a centre of excellence recognized nationally and internationally, in distinctive areas of engineering education and research, based on a culture of innovation and invention"

MISSION

"BIET contributes to the growth and development of its students by imparting a broad based engineering education and empowering them to be successful in their chosen field by inculcating in them positive approach, leadership qualities and ethical values"

QUALITY POLICIES

1. Inculcating the concepts of discipline, punctuality and ethics into the thought process of students to promote their overall growth.
2. Motivating teachers to impart knowledge continuous interaction with students.
3. Carrying out objective evaluation of student's performance.
4. Enhancing the academic skills of the faculty through faculty development programs.
5. Creating an atmosphere conductive to research in the campus.

DEPARTMENT OF CHEMICAL ENGINEERING

VISION AND MISSION

VISION

To train and generate efficient manpower required for effective management of core / allied industries, have a thrust for innovation, undertaking need based research who contributes to Global knowledge and wealth.

MISSION

M1: To offer a quality and efficient undergraduate program in Chemical Engineering required for successful professional career.

M2: To produce graduates who have ability for creative research (thinking) and an urge for continued learning.

M3: To practice sustainability and promote ecofriendly processes which benefit the engineering profession and society.

Program Educational Objectives (PEOs)

1. Ability to advance professionally in their chosen career, wherein they apply their professional and generic skills inculcated during their training.
2. Exhibit leadership qualities and collaborate successfully while working in multidisciplinary teams to tackle multifaceted problems.
3. Ability to design scale up and regulate systems which meet specific needs economic environment public safety.

PROGRAM OUTCOMES (POs)

Engineering Graduates will be able to:

1. Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. Problem Analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. Design/development of Solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. Conduct Investigations of Complex Problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions
5. Modern Tool Usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. The Engineer and Society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. Environment and Sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. Individual and Team Work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and

write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. Project Management and Finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. Life-Long Learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Programme Specific Outcomes (PSOs)

PSO1: Demonstrate the professional and generic skills acquired during their training, needed to apply the principles of chemical engineering in solving real –time problems.

PSO2: Able to undertake independent research and engage themselves in lifelong learning.

PSO3: Play a lead role and exhibit economic, professional and ethical values at their professional career.

SYLLABUS OF MOMENTUM TRANSFER LABORATORY

B. E. CHEMICAL ENGINEERING
Choice Based Credit System (CBCS) and Outcome Based Education (OBE)
SEMESTER - III

MOMENTUM TRANSFER

Course Code	**18CHL37**	CIE Marks	40
Teaching Hours/Week (L:T:P)	(0:2:2)	SEE Marks	60
Credits	02	Exam Hours	03

Course Learning Objectives:

Sl. No.	Experiments
1	Friction in circular pipes.
2	Friction in non-circular pipes.
3	Friction in helical/spiral coils.
4	Flow measurement using venturi/orifice meters (incompressible fluid).
5	Local velocity measurement using Pitot tube.
6	Flow over notches.
7	Hydraulic coefficients – open orifice.
8	Packed bed.
9	Fluidized bed.
10	Study of characteristics for centrifugal , Positive displacement pump
11	Study of various pipe fittings and their equivalent lengths.
12	Compressible fluid flow.
13	Reynolds apparatus.
14	Unsteady flows - Emptying of Tank
15	Bernoulli's Experiment.

Note: Minimum 10 experiments are to be conducted

Course Outcomes: On successful completion of this course students will be able.

CO1: Identify, name, and characterize flow patterns and regimes.

CO2: Write basic units of measurement, convert units, and appreciate their magnitudes.

CO3: Measure fluid pressure and relate it to flow velocity.

CO4: Demonstrate practical understanding of friction losses, coefficient of discharge and efficiency in internal flows and pumps.

CO5: Explain fluid flow in channels and application of flow meters and notches.

CO6: Demonstrate the ability to write clear lab reports

Conduct of Practical Examination:

1. All laboratory experiments are to be included for practical examination.
2. Breakup of marks and the instructions printed on the cover page of answer script to be strictly adhered by the examiners.
3. Students can pick one experiment from the questions lot prepared by the examiners.
4. Change of experiment is allowed only once and 15% Marks allotted to the procedure part to be made zero.

REFERENCE BOOKS:

1. McCabe, W.L., *et.al.*, "Unit Operations in Chemical Engineering", 5th edn., McGraw Hill, New York 1993
2. Kumar K.L., "Engineering Fluid Mechanics", Eurasia Publishing House (p) Ltd., New Delhi, 3rd edn. 1984.
3. Dr R K Bansal., "A Text Book of Fluid Mechanics" 1st edn., Laxmi Publications (P) Ltd., New Delhi. 2005.
4. Coulson J.H. and Richardson J.F., "Chemical Engineering", Vol-I, 5th edn., Asian Books (p) Ltd., New Delhi, 1998.
5. Badger W.L. and Banchero J.T., "Introduction to Chemical Engineering", Tata McGraw Hill, New York, 1997.

CONTENTS

LABORATORY INSTRUCTIONS:

1. Every student should enter with a copy of the laboratory manual, record book and rough book.

2. Dress code: Students must come to the laboratory wearing: (1) Apron, (ii) Decent dress and (iii) Leather shoes.

3. To avoid any injury, the student must take the permission of the laboratory staff before handling the machines.

4. Students must ensure that their work areas are clean.

5. At the end of each experiment, the student must take initials from the staff on your data/observations.

6. Laboratory report must be submitted in standard format, in the subsequent lab turn. Reports on ordinary sheets and computer paper will not be accepted.

7. Each member of any group must submit lab report even if the experiment hasbeen performed in a group.

8. The lab report must contain: (1) Title of the experiment, (ii) Three to four lines stating the objectives, (iii) A few lines on background; (iii) Name of all equipments/tools used along with one line description of its use.

9. Student can check their laboratory reports after correction for discussion.

10. Careless handling of machine will not be tolerated.

11 Be in time, don't muddle with other equipments

12 Complete all calculations, draw graphs, and arrive at proper conclusions, get staff signature.

SAFE HANDLING OF CHEMICALS

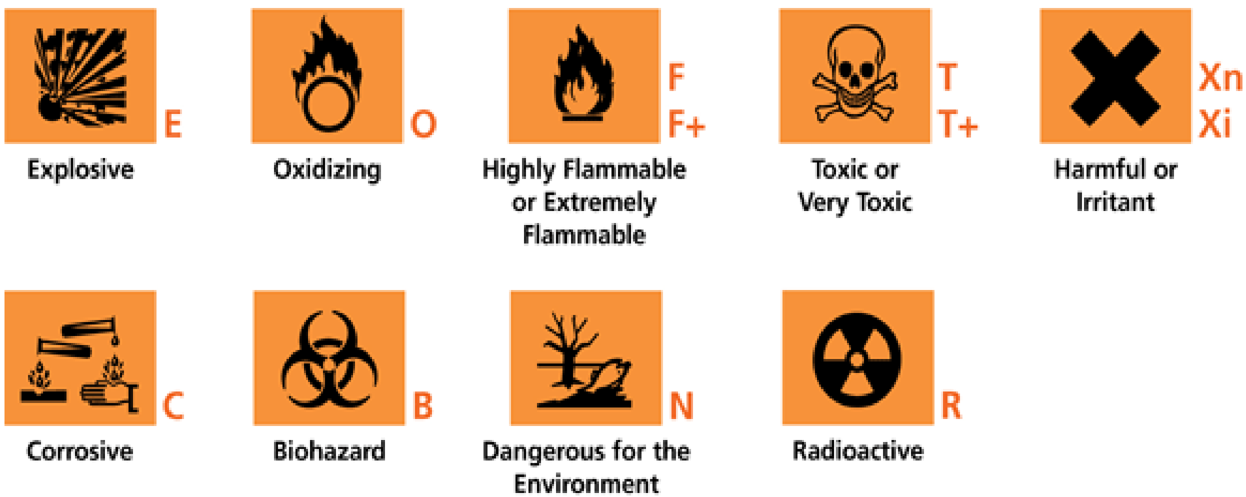
Working with potentially harmful chemicals is an everyday occurrence in a laboratory. Students are requested to inform themselves about toxicological information and procedures for handling and storage of chemicals used.

For most commercially available substances, detailed instructions are available in the Material Safety Data Sheet (MSDS). Gathering General Information on Chemicals

The Material Safety Data Sheet (MSDS) describes properties, reactivates, potential chemical hazards, and safe handling procedures for commercially available chemicals you are working with. These sheets must be archived in a specified folder; all lab personnel must know where it is kept. This MSDS log must be updated at regular intervals. Information that is contained in the

Material Safety Data Sheets is also required by law to be conveyed to employees on a chemical-by-chemical basis.

MSDSs are generally written for chemicals that are used in the industrial setting therefore some of the information provided on the MSDS may not be applicable to laboratory usage. The use of chemicals in a laboratory is generally in a more controlled environment than in the industrial setting and much smaller quantities of the chemical are being used at any one time. Nevertheless, a great deal of information on hazards associated with laboratory chemicals can be obtained by reading the MSDS. Familiarize yourself with the **PICTOGRAMS AND HAZARD CODES** widely used to mark risks.



Risk and Safety Phrases are widely used and should be known by any user when handling chemicals in the course of laboratory procedures.

Handling and Transportation of Chemicals: Many laboratory accidents occur by carrying chemicals from one place to another or transferring them from one container to another. The chemicals used in a laboratory are often corrosive, toxic or flammable and any accident involving these has the potential for personal injury. Therefore, it is good practice to assume that all chemicals are potentially hazardous. When large bottles of acids, solvents, or other liquids are transported within the laboratory without a cart, only one bottle should be carried at a time. The bottle should be carried with both hands, one on the neck of the bottle and the other underneath. Do not hook a finger through the glass ring on top of the bottle, allowing it to dangle while being transported. Never carry or attempt to pick up a bottle by the cap.

Large quantities of concentrated mineral acids, e.g., sulfuric, nitric and hydrochloric acids, shall be kept in specific storage rooms or cabinets for corrosive substances.

EXPERIMENT NO. 01

FRICTION IN CIRCULAR PIPES

1. **AIM AND OBJECTIVE**

   i. To study the principles of fluid flow through pipes.
   ii. To study a) Laminar flow b) Turbulent flow
   iii. To determine the frictional losses encountered in a hydraulically smooth pipe under laminar and turbulent flow situations.
   iii. To determine the effect of Reynolds number on Fanning friction factor for laminar and turbulent flow situations in a hydraulically smooth pipe.
   iv. To tabulate the experimental result and calculate the friction for each flow.
   v. To plot a graph of f Vs N_{Re} for a given pipe.

2. **BACKGROUND INFORMATION AND THEORY**

A fundamental understanding of fluid flow is essential to almost every industry related with chemical engineering. In the chemical and manufacturing industries, large flow networks are necessary to achieve continuous transport of products and raw materials from different processing units. This requires a detailed understanding of fluid flow in pipes. Energy input to the gas or liquid is needed to make it flow through the pipe. This energy input is needed because there is frictional energy loss (also called frictional head loss or frictional pressure drop) due to the friction between the fluid and the pipe wall and internal friction within the fluid. In pipe flow substantial energy is lost due to frictional resistances.

Pipe losses in a piping system result from a number of system characteristics, which include among others; pipe friction, changes in direction of flow, obstructions in flow path, and sudden or gradual changes in the cross-section and shape of flow path.

Resistance to flow in a pipe when a fluid flows through a pipe, the internal roughness of the pipe wall can create local eddy currents within the fluid adding a resistance to flow of the fluid. The velocity profile in a pipe will show that the fluid elements in the center of the pipe will move at a higher speed than those closer to the wall. . Therefore friction will occur between layers within the fluid. This movement of fluid elements relative to each other is associated with pressure drop, called frictional losses. Pipes with smooth walls such as glass, copper, brass and polyethylene have only a small effect on the frictional resistance. Pipes with less smooth walls such as concrete, cast iron and steel will create larger eddy currents which will sometimes have a significant effect on the frictional resistance. Rougher the inner wall of the pipe more will be the pressure loss due to friction.

As the average velocity increases, pressure losses increase. Velocity is directly related to flow rate.

Velocity=Volumetric flow rate /Cross sectional area of the pipe.

An increase or decrease in flow rate will result in a corresponding increase or decrease in velocity. Smaller pipe causes a greater proportion of the liquid to be in contact with the pipe, which creates friction. Pipe size also affects velocity. Given a constant flow rate, decreasing pipe size increases the velocity, which increases friction. The friction losses are cumulative as the fluid travels through the length of pipe. The greater the distance, the greater the friction losses will be. Fluids with a high viscosity will flow more slowly and will generally not support eddy currents and therefore the internal roughness of the pipe will have no effect on the frictional resistance. This condition is known as laminar flow.

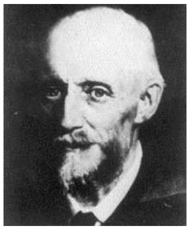
There are in general three types of fluid flow in pipes

a. Laminar flow - generally happens when dealing with small pipes, low flow velocities and with highly viscous fluids. At low velocities fluids tend to flow without lateral mixing, and adjacent layers slide past one another like playing cards. There are neither cross currents nor eddies. Laminar flow can be regarded as a series of liquid cylinders in the pipe, where the innermost parts flow the fastest, and the cylinder touching the pipe isn't moving at all.
b. Turbulent flow -the fluid moves erratically in the form of cross currents and eddies. Turbulent flow happens in general at high flow rates and with larger pipes.
c. Transitional flow- is a mixture of laminar and turbulent flow, with turbulence in the center of the pipe, and laminar flow near the edges.

Reynolds studied the conditions under which one type of flow changes into the other and found that the critical velocity, at which laminar flow changes into turbulent flow, depends on four quantities:

i. The diameter of the tube,
ii. Viscosity,
iii. Density and
iv. Average velocity of the liquid.

He found that these four factors can be combined into one group and that the change in kind of flow occurs at a definite value of the group. The grouping of the variables so found was Reynolds Number (N_{Re}) .Turbulent or laminar flow is determined by Reynolds Number. The Reynolds number expresses the ratio of inertial (resistant to change or motion) forces to viscous forces.



$$N_{Re} = \frac{D\rho V}{\mu} = \frac{inertia\,force}{viscous\,force}$$

Osbourne Reynolds
(1842-1912)

Where , D is the diameter of the pipe
ρ is the density of fluid
V is the average velocity of the fluid
μ is the viscosity of fluid.
The Reynolds number can be written in terms of kinematic viscosity (η)
η= dynamic viscosity / density=μ/ρ

The Reynolds number is important in analyzing any type of flow when there is substantial velocity gradient (i.e. shear). It indicates the relative significance of the viscous effect compared to the inertia effect. The flow is laminar when N_{Re}< 2100, turbulent when 2100 < N_{Re}< 4000and transient when 4000 < N_{Re}.

At laminar region, viscous forces are dominant as compared to inertial forces. Under laminar flow condition the pressure drop per unit length is proportional to the velocity. At transition region, the experimental results are not reproducible. Finally, at turbulent region, inertial forces are dominant. For turbulent flow, the pressure drop becomes proportional to the velocity raised to a power of 2.

Relationship Between Frictional Head Loss and Frictional Pressure Drop

The energy loss in pipe flow due to friction can be expressed as a pressure drop instead of as a head loss. Chemical and mechanical engineers often work with pressure drop, whereas civil engineers usually work with head loss. The relationship between frictional head loss and frictional pressure drop is simply:

$$(-\Delta P)_f = \rho g h_{fs}$$

Where:
$(-\Delta P)_f = \rho g h_{fs}$ = frictional pressure drop,
h_{fs} = frictional head loss due to skin friction,
ρ = fluid density,
g = acceleration due to gravity
Head Loss due to skin friction (h_{fs}) can be related to wall shear.

$$h_{fs} = (-\Delta P)_{fs}/\rho g = \frac{4\tau_w L}{\rho g D}$$

Where,
τ_w - shear stress at the wall of the pipe, L is the length of the pipe and ΔP_f is pressure drop due to friction losses.

τ_w - not conveniently determined so the dimensionless friction factor is introduced into the equations.

The Friction Factor It is denoted by f and defined as the ratio of the wall shear stress to the product of the velocity head (V2/2) and density=

$$f = \frac{\tau_w}{\rho V^2/2}$$

$$\frac{wall shear\, stress}{density * velocityhead} \; h_{fs} = \frac{-(\Delta P)_f}{\rho g} = 4f(\frac{L}{D})(\frac{\overline{V}^2}{2g})$$

Where,

f is the Fanning's friction factor

- Only need L, D, V and f to get friction loss
- Valid for both laminar and turbulent flow
- Valid for Newtonian and Non-Newtonian fluids

Correlations were made between the fanning friction factor and the Reynolds number for both laminar and turbulent flow in a variety of pipes.

For laminar flow, first principles can be used to develop a relation between Reynolds number and friction factor. The Hagen-Poiseuille equation relates the frictional pressure drop to fluid velocity, viscosity, and pipe dimension:

$$-(\Delta P)_f = \frac{32\mu VL}{D^2}$$

Equating the pressure drop due to friction in the Hagen-Poiseuille equation, with the overall pressure drop across the pipe, and combining with the Fanning equation results in relation for laminar flow as

$f=16/N_{Re}$

A first principle analysis cannot be used to develop a relation between friction factor and Reynolds numbers for turbulent flow. A variety of empirical correlations exist for turbulent flow in smooth pipes. Blasius equations :

$$f_{blasius} = \frac{0.079}{N_{Re}^{0.25}}$$

The above correlation is valid for $4000 < N_{Re} \leqslant 10^5$

The Blasius equation is purely an empirical equation and has no theoretical basis, but it is a convenient form for application. The entire turbulent region can be represented by the von Kármán-Nikuradse equation:

$$\frac{1}{\sqrt{f}} = 4.0 log N_{Re}\sqrt{f} - 0.4$$ for Re > 4000, turbulent

It has long been known that in turbulent flow a rough pipe leads to a larger friction factor for a given Reynolds number than a smooth pipe does. If a rough pipe is smoothed, the friction factor is reduced. When further smoothing brings about no further reduction in friction factor for a given Reynolds number, the tube is said to be hydraulically smooth.

In turbulent flow, the friction factor, f depends upon the Reynolds number and on the relative roughness of the pipe, k/D, where, k is the roughness parameter (average roughness height of the pipe) and D is the inner diameter of the pipe. . The general behavior of turbulent pipe flow in the presence of surface roughness is well established. When k is very small compared to the pipe diameter D i.e. k/D >0, f depends only on N_{Re}. When k/D is of a significant value, at low N_{Re}, the flow can be considered as in smooth regime (there is no effect of roughness). As N_{Re} increases, the flow becomes transitionally rough, called as transition regime in which the friction factor rises above the smooth value and is a function of both k and N_{Re} and as N_{Re} increases more and more, the flow eventually reaches a fully rough regime in which f is independent of N_{Re} .

In a smooth pipe flow, the viscous sub layer completely submerges the effect of k on the flow. In this case, the friction factor f is a function of N_{Re} and is independent of the effect of k on the flow. In case of rough pipe flow, the viscous sub layer thickness is very small when compared to roughness height and thus the flow is dominated by the roughness of the pipe wall and f is the function only of k/D and is independent of N_{Re} . For design purposes, the frictional characteristics of round pipes, both smooth and rough, are summarized by the friction factor chart, which is a log-log plot of Fanning friction factor (f) vs. N_{Re} which is based on Moody's chart.

3. APPARTUS USED

i. Flow through pipe experimental set up
ii. Stop watch
iii. Manometer
iv. Meter scale

4. EXPERIMENTAL SET UP

5. EXPERIMENTAL PROCEDURE

i. Ensure 75% of the sump is filled with clean water.
ii. Open the inlet valve leading to the smooth pipe and valves leading to other lines closed. Close the bypass valve pump.
ii. Switch on the pump and remove the air bubbles trapped in the manometer tube.
iii. Maintain a steady flow of water.

iv. Record the level of manometer fluid in left and right limbs of manometer.

v. Note down the time taken for 100 cm rise in water level in collection tank. (ensure that outlet butterfly valve is closed).

vi. Increase the flow rate of water by opening the main valve and throttling the bypass valve suitably and repeat step 4 and 5.

6. DATA

i. Diameter of the pipe, D_1 = ……….. m D_2= ……… m

ii. Length of pipe, L_1=L_2 =………… m

iii. Area of the tank, A_T = Length X Breadth, m A_T…………m

iv. Density of water, ρ_w = 1000 kg/m^3

v. Viscosity of water, μ_w= $0.76x10^{-3}$kg/m-s

vi. Density of Mercury, ρ_m = 13600 kg/m^3

vii. Acceleration due to gravity, g=9.81 m/s^2

7. NOTATIONS

i. H_1 – Height of mercury in right limb, m

ii. H_2 – Height of mercury in left limb, m

iii. ΔH – Manometer liquid difference, m

iv. h_1 –Initial height of water level in measuring tank, m

v. h_2 –Final height of water level in measuring tank, m

vi Δh – Water level rise in measuring tank , m

vii t – Time taken for rise in water level, s

viii V – Volume of water collected, m^3

ix. Q – Volumetric flow rate, m^3/s

x. A_1 – Cross sectional area of pipe 1, m^2

xi. A_2 – Cross sectional area of pipe 2, m^2

xii u- Velocity of fluid flow in pipe, m/s

xiii. N_{Re} – Reynolds number, Dimensionless

xiv f – friction factor for laminar flow, $N_{Re} < 2100$

xv. f_t – friction factor for turbulent flow, $N_{Re} > 4000$,

xvi. ΔP – Pressure drop, N/m^2

xvii. f_o – Experimental friction factor

8. FORMULAE

i. $\Delta H = H_1 - H_2$, m

ii. $\Delta h = h_1 - h_2$, m

iii. $A_T = LXB$, m^2

iv. $V_w = LXBX\Delta h$, m^3

v. $Q = V/t$, m^3/s

vi. $A_1 = \pi D_1^2/4$, m^2 $A_2 = \pi D_2^2/4$, m^2

vii. $V = Q/A$, m/s

viii. $N_{Re} = DV\rho/\mu$

ix. $f = 16/ N_{Re}$, for laminar flow, $N_{Re} < 2100$

x. $f_t = 0.079\ N_{Re}^{-1/4}$,friction factor for turbulent flow, $N_{Re} > 4000$,

xi. $\Delta P – \rho_m g \Delta H$, N/m^2

xii. $f_o – \Delta PD/2L\ \rho_w u^2$

9. OBSERVATION TABLE

i. For pipe of dia, D_1= …………mm

Sl. No.	Manometer reading, m				Water level reading, m				Time, s
	H_1 mm	H_2 mm	ΔH mm	ΔH m	h_1 mm	h_2 mm	Δh mm	Δh m	
1.									
2.									
3.									
4.									
5.									
6.									

ii. For pipe of dia, D_2= …………mm

Sl. No.	Manometer reading, m				Water level reading, m				Time, s
	H_1 mm	H_2 mm	ΔH mm	ΔH m	h_1 mm	h_2 mm	Δh mm	Δh m	
1.									
2.									
3.									
4.									
5.									
6.									

10. SAMPLE CALCULATIONS

11. CALCULATION TABLE

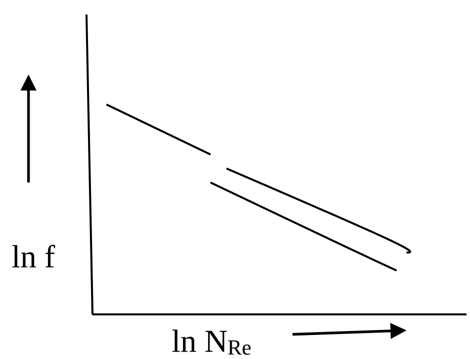
i. For pipe of dia, D_1= ………..mm

Sl. No.	ΔH m	Δh m	t s	Q m^3/s	u m/s	N_{Re}	ln N_{Re}	f_t	ln f_t	ΔP N/m^2	f_o

ii. For pipe of dia, D_2= ………..mm

Sl. No.	ΔH m	Δh m	t s	Q m^3/s	u m/s	N_{Re}	ln N_{Re}	f_t	ln f_t	ΔP N/m^2	f_o

12. NATURE OF GRAPH



13. RESULTS

14. DISCUSSION ON RESULTS

15. PRACTICAL APPLICATIONS OF EXPERIMENTAL STUDY

16. VIVA QUESTIONS

i. What is shear stress?
ii. What is skin friction?
iii. What is friction factor?
iv. What is laminar and turbulent flow?
v. What are Newtonian fluids?
vi. What is roughness parameter?

17. REFERENCE

i. McCabe, W.L., *et.al.*, **"**Unit Operations in Chemical Engineering**"**, 5th edn., McGraw Hill, New York 1993.
ii. Chemical Engineers Handbook, Perry & Green, 8th edn, McGraw Hill, 1997.
iii. Badger W.L. and Banchero J.T., "Introduction to Chemical Engineering", Tata McGraw Hill, New York 1997
iv. Coulson J.H. and Richardson J.F., "Chemical Engineering", Vol-I, 5th edn., Asian Books (p) Ltd., New Delhi, 1998.

EXPERIMENT NO. 02

FLOW MEASUREMENT USING VENTURIMETER

1. AIM AND OBJECTIVE

i. To study the principle, operation and application of Venturimeter.
ii. To conduct an experiment using given Venturimeter and to determine the Venturimeter coefficient.
iii. To plot the graph of Q_{act} vs $\sqrt{H_w}$

2. BACKGROUND INFORMATION AND THEORY

Venturi meter is a flow measurement device, which is based on the principle of Bernoulli's equation. Inside the pipe pressure difference is created by reducing the cross-sectional area of the flow passage. This difference in pressure is measured with the help of manometer and helps in determining rate of fluid flow or other discharge from the pipe line. Venturi meter has a cylindrical entrance section, converging conical inlet, a cylindrical throat and a diverging recovery cone.

<u>Components of Venturimeter:</u>

a) **Cylindrical entrance section:** This is the section having the size of a pipe to which it is attached. The venturi meter should be proceeded by a straight pipe of not less than 5 to 10 times the pipe diameter and free from fittings, misalignment and other source of large scale turbulence.

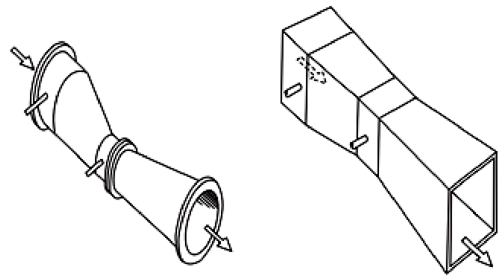
b) **Converging conical section:** The converging takes place at an angle of 21±2°. The velocity of fluid increases as it passes through the converging section and correspondingly the static pressure falls.

c) **Throat:** This is a cylindrical section of minimum area. The velocity is maximum and the pressure is minimum. The throat diameter is usually between ½ to ¼ of the inlet diameter. Length of the throat equals its diameter.

d) **Diverging section:** This is a section in which there is a change of stream area back to the entrance area. The recovery of kinetic energy by its conversion to pressure energy is nearly complete and so the overall pressure loss is small. To accomplish a maximum recovery of kinetic energy the diffuser section is made with an included angle of 5° to 7°. This angle has to be kept less so that the flowing fluid has least tendency to separate out from the boundary of the section.

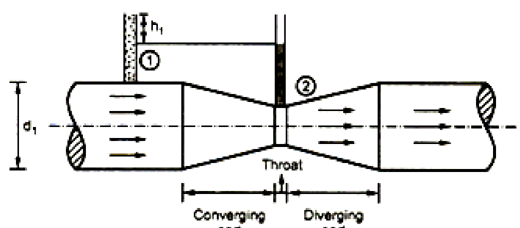
Types of Venturi Tubes

- standard long-form or classic venturi tube
- modified short form where the outlet cone is shortened
- an eccentric form to handle mixed phases or to minimize build-up of heavy materials
- rectangular form used in duct work



(a) Eccentric type and (b) Rectangular venturi type

The major disadvantages of this type of flow detection are the high initial costs for installation and difficulty in installation and inspection. The Venturi effect is the reduction in fluid pressure that results when a fluid flows through a constricted section of pipe. The fluid velocity must increase through the constriction to satisfy the equation of continuity, while its pressure must decrease due to conservation of energy: the gain in kinetic energy is balanced by a drop in pressure or a pressure gradient force. An equation for the drop in pressure due to venturi effect may be derived from a combination of Bernoulli's principle and the equation of continuity.



Let d_1 = Diameter at inlet or at section 1

V_1 = velocity of fluid at section 1

a_1 = Area at inlet = $\frac{\pi d_1^2}{4}$

P1 = Pressure at section 1

and d_2, V_2, a_2 and P_2 are the corresponding values at section 2.

Applying Bernoulli's equations at section 1 and section 2, we get,

$$\frac{P_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{P_2}{\rho g}+\frac{v_2^2}{2g}+z_2 \text{ ---------(1.1)}$$

Since the pipe is horizontal, so z1 = z2

$$\frac{P_1}{\rho g}+\frac{v_1^2}{2g}=\frac{P_2}{\rho g}+\frac{v_2^2}{2g}$$

$$\frac{P_1-P_2}{\rho g}=\frac{v_2^2-v_1^2}{2g} \text{ ---------(1.2)}$$

But $\frac{P_1-P_2}{\rho g}$ difference of pressure head at section 1 and 2 = h --------(1.3)

substituting this value of $\frac{P_1-P_2}{\rho g}$ = h in equation (1.2)

$$h=\frac{v_2^2-v_1^2}{2g} \text{ ---------(1.4)}$$

Now applying continuity equation at section 1 and 2

$a_1v_1=a_2v_2$ or $v_1=\frac{a_2v_2}{a_1}$

Substituting value of v1 in equation (1.4) we get

$$h=\frac{v_2^2}{2g}-\frac{(\frac{a_2v_2}{a_1})^2}{2g}$$

$$=\frac{v_2^2}{2g}-\frac{(a_2^2v_2^2)}{a_1^2 2g}$$

$$=\frac{v_2^2}{2g}\ (1-\frac{a_2^2}{a_1^2})$$

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

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

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

$$v_2=\frac{a_1}{\sqrt{a_1^2-a_2^2}}\sqrt{2gh} \qquad (h=x(1-\frac{\rho_L}{\rho}))$$

Where x = difference between the liquid column in U tube,

ρ_L = density of lighter liquid,

ρ = density of liquid flowing through pipe.

But, discharge through venturimeter,

$Q= a_2v_2$

$$v_2 = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh} \text{ ------(1.5)}$$

$Q = C\sqrt{h}$, where C= constant of venturi meter.

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

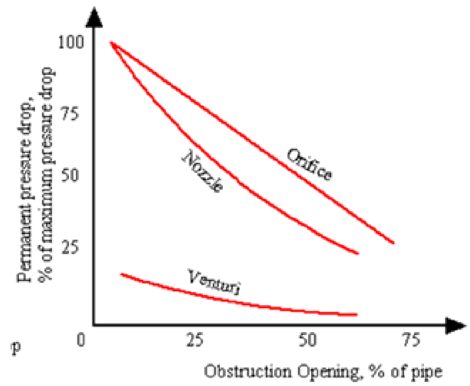
Equation (1.5) gives the discharge under ideal conditions and is called as theoretical discharge.

Actual discharge is given by,

Actual discharge = Coefficient of venturimeter x Theoretical discharge

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

Recovery of Pressure Drop in Orifices, Nozzles and Venturi Meters:



The pressure drop in orifice meter and nozzles are significantly higher than the venture meters. Venturi causes less overall pressure loss in a system and thus saves energy: the overall pressure loss is generally between 5 and 20 per cent of the measured differential pressure. The venturi meter has an advantage over the orifice plate in that it does not have a sharp edge which can become rounded; however, the venturi meter is more susceptible to errors due to burrs or deposits round the downstream (throat) tapping. The lengths of straight pipe required for upstream and downstream of a venturi meter for accurate flow measurement are given in ISO 5167-1: 1991.

3. APPARTUS

i. Venturimeter
ii. Pipeline
iii. Tank
iv. Control valve
v. Manometer
vi. Stopwatch

4. EXPERIMENTAL SET UP

5. EXPERIMENTAL PROCEDURE

i. Ensure 75% of the sump is filled with clean water.
ii. Open the inlet valve of the Venturimeter and close by pass valve of the pump.
iii. Start the pump and remove the air trapped in the manometer tube.
iv. Maintain a steady flow of water.
v. Record the level of manometer fluid in left and right limbs of manometer.
vi. Record the time taken for 50cm rise in water level in collection tank (Ensure that outlet butterfly valve is closed).
vii. Repeat step iv to vi for various positions of bypass valve of the pump (fully closed to partial close).

6. DATA

i. Inlet diameter of Venturimeter pipe, D_p =
ii. Throat diameter of Venturimeter, D_v =
iii. Area of the tank, A_T = Length X Breadth, m A_T…………m
iv. Density of water, $\rho_w = 1000$ kg/m^3
v. Density of Mercury, $\rho_m = 13600$ kg/m^3
vi. Viscosity of water, $\mu_w = 0.76 \times 10^{-3}$kg/m-s
vii. Acceleration due to gravity, g=9.81 m/s^2

7. NOTATIONS

i. H_1 – Height of mercury in right limb, m
ii. H_2 – Height of mercury in left limb, m
iii. ΔH – Manometer liquid difference, m
iv. h_1 –Initial height of water level in measuring tank, m
v. h_2 –Final height of water level in measuring tank, m
vi. Δh – Water level rise in measuring tank , m
vii. t – Time taken for rise in water level, s
viii. V_w – Volume of water collected, m^3
ix. H_w – Head in meters of water, m
x. A_1 – Cross sectional area of pipe , m^2
xi. A_2 – Cross sectional area of throat of Venturimeter , m^2
xii. V- Velocity of fluid flow in pipe, m/s

xiii. Q_{Act} – Actual volumetric flow rate, m^3/s
xiv. Q_{Th} - Theoretical volumetric flow rate, m^3/s
xv. ΔP – Pressure drop, N/m^2
xvi. C_d – Coefficient of discharge
xvii. m – slope from graph

8. FORMULAE

i. $\Delta H = H_1 - H_2$, m
ii. $\Delta h = h_1 - h_2$, m
iii. $A_T = LXB$, m^2
iv. $V_w = LXB X \Delta h$, m^3
v. $Q_{Act} = V_w / t$, m^3/s
vi. $H_w = \Delta H(\rho_m / \rho_w - 1)$ m of water
vii. $A_1 = \pi D_p^2/4$, m^2 $A_2 = \pi D_v^2/4$, m^2
viii. $Q_{Act} = C_d (A_1 A_2 / \sqrt{(A_1^2 - A_2^2)})\sqrt{2g H_w}$, m^3/s
Plot of Q_{Act} vs. $\sqrt{H_w}$
$m = \text{slope} = C_d (A_1 A_2 / \sqrt{(A_1^2 - A_2^2)})\sqrt{2g}$
$C_d = m \sqrt{(A_1^2 - A_2^2)} / A_1 A_2 \sqrt{2g}$
C_d = ……….
ix. $Q_{Th} = Q_{Act} / C_d$, m^3/s
x. $\Delta P = (\rho_m - \rho_w)\, g\, \Delta H$, N/m^2

9. OBSERVATION TABLE

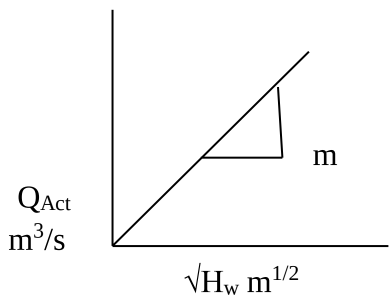
Sl. No.	Manometer reading, m				Water level reading, m				Time, s
	H_1 mm	H_2 mm	ΔH mm	ΔH m	h_1 mm	h_2 mm	Δh mm	Δh m	
1.									
2.									
3.									
4.									
5.									
6.									

10. SAMPLE CALCULATIONS

11. CALCULATION TABLE

Sl. No.	ΔH m	t s	Δh m	Q_{Act} m^3/s	H_w m of H_2O	$\sqrt{H_w}$ $m^{1/2}$	Q_{Th} m^3/s	ΔP N/m^2
1.								
2.								
3.								
4.								
5.								
6.								

12. NATURE OF GRAPH



$m = \text{slope} = C_d \,(A_1 A_2 / \sqrt{(A_1^2 - A_2^2)})\sqrt{2g}$

13. RESULTS

14. DISCUSSION ON RESULTS

15. PRACTICAL APPLICATIONS OF EXPERIMENTAL STUDY

16. VIVA QUESTIONS

i. What is Venturimeter? Explain its principle.
ii. Define C_d.
iii. As velocity increases what happens to pressure in Venturimeter?
iv. Mention the parts of Venturimeter.

17. REFERENCE

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EXPERIMENT NO. 03

FLOW THROUGH PACKED BED

1. AIM AND OBJECTIVE

i. To study the basic principles, type and equipment used and industrial application of Packed bed.
ii. To determine the effect of superficial mass velocity on pressure drop across the packed bed with liquid flow.
iii. Determine the effect of modified Reynolds number on modified friction factor.
iii. To verify Ergun's equation of fluids through packed bed.
iv. To obtain pressure drop correlation for the given packed bed.

2. BACKGROUND INFORMATION AND THEORY

Chemical Engineering operations commonly involve the use of packed beds. These are devices in which a large surface area of contact between a liquid and a gas, or a solid and a gas or liquid is obtained for achieving rapid mass and heat transfer and for chemical reactions.

Packed bed column is a cylindrical column packed with certain packing material. The packing can be randomly filled with small objects like Raschig rings or else it can be a specifically designed structured packing. Several chemical engineering unit operations such as absorption, adsorption, distillation and extraction are carried out in packed columns. These packings enhance the surface area available for transfer operations. Packed columns are also used for heterogeneous catalytic reactions. The packed bed configuration also facilitates the intimate mixing of fluids with mismatched densities, largely due to increased surface area for contact.

Flow through a packed bed can be regarded as fluid flow past some number of submerged objects. When there is no flow through the packed bed, the net gravitational force (including buoyancy) acts downward. When flow begins upward, friction forces act upward and counterbalance the net gravitational force. The frictional force can be expressed in terms of a friction factor. This leads to equations describing the flow of a fluid past a collection of particles. From a fluid mechanical perspective, the most important issue is that of the pressure drop required for the liquid or the gas to flow through the column at a specified flow. The pressure losses accompanying the flow of fluids through packed columns are caused by simultaneous kinetic and viscous energy losses. The essential factors determining the energy loss, i.e. pressure drop, in packed beds are:

1. Rate of fluid flow
2. Viscosity and density of the fluid
3. Closeness and orientation of packing
4. Size shape and surface of the particles

The first two variables concern the fluid, while the last two the solids. To calculate the pressure losses, we rely on a friction factor correlation attributed to Ergun.

The frictional force can be expressed in terms of a friction factor. This leads to equations describing the the flow of a fluid past a collection of particles. There are several approaches to treating fluid flow through packed beds. The most successful of these is the Ergun Equation, which describes flow in both the laminar and turbulent regimes. This method treats the packed column as a compact irregular bundle of tubes. Modifying the theory for straight tubes not only takes into account the irregularity of the tubes, but yields relationships similar to those derived for straight tubes as well.

This analysis assumes several conditions. First, we assume that the particles are packed in random; there is no channeling in the packed bed. Channeling occurs when the fluid flowing through the packed bed finds a "preferred path" through the bed. We also assume that the diameter of the packing is much smaller than the diameter of the column as well. The maximum recommended particle diameter is one-fifth of the column diameter. We assume that velocity, particle diameter and void fraction behaves as a bulk behavior and hence we can use an average values. The Ergun equation is

$$f_p = \frac{150(1-\epsilon)}{\frac{\phi_s D_p V_0 \rho}{\mu}} + 1.75$$

fp is the friction factor for a packed bed called as modified friction factor. Where

$$f_p = \frac{\Delta P \phi_s D_p \epsilon^3}{\rho V_0^2 L(1-\epsilon)}$$

With ΔP = pressure drop

L= height of the bed

μ= fluid viscosity

ϵ= fluid viscosity

V_o = fluid superficial velocity

Dp = particle diameter

ρ = density of the fluid

φ_s = sphericity of the particle.

Ergun equation was obtained by fitting the data for spheres, cylinders and crushed solids such as coke and sand. For Raschig rings and Berl saddles, which have porosities of 0.55 to 0.75, Ergun equation predicts pressure drops lower than those found experimentally. It also does not apply well to other tower packings of high surface area and high porosity.

It is seen from the formula that when the flow is high, the turbulent part of the formula appears; likewise, when the flow is low, the laminar part of the formula comes out. Thus, the Ergun equation can be used for any type of flow. The Ergun equation tells us a number of things. It tells us the pressure drop along the length of the packed bed given some fluid velocity. It also tells us that the pressure drop depends on the packing size, length of bed, fluid viscosity and fluid density.

At low Reynolds numbers, the quantity 1.75 of Eq.(1) is negligible in comparison with Reynolds number term. This implies that the viscous forces control and that inertial force are unimportant. Then we have

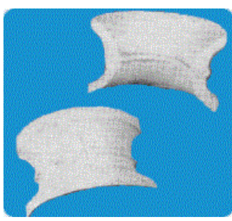
$$\frac{\Delta P \phi_s^2 D_p^2 \epsilon^2}{\rho V_0 L \mu (1-\epsilon)^2} = 150$$

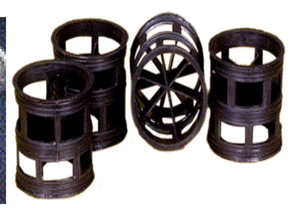
This is called the Kozeny-Carman equation and is a laminar flow equation, to be used when N_{Rep} is less than about 1.

For a given system it indicates that the pressure drop is directly proportional to the flow rate. For large Reynolds numbers, above about 1000,the first term on the right hand side of Eq.(1) fades out as viscous forces become negligible and inertial forces control , Then

$$\frac{\Delta P \phi_s D_p \epsilon^3}{\rho V_0^2 L (1-\epsilon)} = 1.75$$

This is Blake Plummer equation. For large Reynolds numbers, above about 1000 pressure drop is propotional to square of velocity. In addition to Ergun' correlation, another model, the Leva's equation is commonly utilized in the prediction of pressure drop versus flow rate. Leva's equation, based on the study of single incompressible fluids through an incompressible bed of granular salts, is relatively similar to the structure of the Ergun equation.






Intalox saddles Berl saddles Pall rings Raschig rings

3. APPARTUS USED

i. Packed bed column
ii. Packing material
iii. Manometer
iv. Meter scale
v. Stop watch
vi. Bucket

4. EXPERIMENTAL SET UP

5. EXPERIMENTAL PROCEDURE

i. Connect the manometer at the points provided.
ii. Switch on the pump with the by-pass valve opened fully.
iii. Initially adjust the flow rate very slowly through the bed.
iv. Remove all the air entrapped in the system by opening the valves on the top of manometer simultaneously and ensure that all air bubbles are removed.
v. Switch off the pump and determine the voidage by noting down amount of water collected in the bed.
vi. Start the pump and adjust the flow rate at maximum level.
vii. Note down the corresponding manometer reading.
viii. Note down the amount of water collected from the bed and time required to collect the water.
ix. Slowly decrease the flow rate and repeat step vii to viii for at least 6 readings.
x. Calculate V_{oexp} and N_{Re} for the various flow rates.
xi. Plot a graph of pressure drop per unit length of bed v/s V_{oexp}.
xii. Calculate friction factor v/s N_{Re}. Observe the nature of flow for the given packed bed.

6. DATA

i. Length of packed bed, $L = 890 \times 10^{-3}$, m
ii. Actual pipe (column) diameter, $D_t = 75 \times 10^{-3}$, m
iii. Empty column fluid velocity, V = 0.0249 m/s
iv. Sphericity of flowing fluid, $\Phi s = 0.65$
v. Average particle diameter of packed bed, $D_p = 9 \times 10^{-3}$ m
vi. Bed Porosity, € = 0.34
vii. Density of water, $\rho_w = 1000$ kg/m^3
viii. Viscosity of water, $\mu_w = 0.76 \times 10^{-3}$ kg/m-s
ix. Density of Mercury, $\rho_m = 13600$ kg/m^3
x. Acceleration due to gravity, g=9.81 m/s^2

7. NOTATIONS

i. H_1 – Height of mercury in right limb, m
ii. H_2 – Height of mercury in left limb, m
iii. ΔH – Manometer liquid difference, m
iv. m – Amount of water collected, kg
v. t – Time taken to collect water, s
vi A– cross-sectional area of empty tower, m^2
vii D_t – Diameter of empty column, m
viii. V_{oexp} – Experimental fluid superficial velocity based on chamber cross section, m/s
ix. N_{Re} – Reynolds number, Dimensionless
x. ΔP – Pressure drop, N/m^2

xi. $\Delta P/L$ – Pressure drop across packed bed/unit length, N/m^3
xii $V_{mf\ (the)}$ – minimum fluidization velocity, m/s
xiii. V_{othe} – Theoretical fluid superficial velocity based on chamber cross section, m/s

8. FORMULAE

i. $\Delta H = H_1 + H_2$, m
ii. $A = \pi D_t^2/4$, m^2
iii. $D_{eq} = 2D_p\phi_s€/3(1-€)$, m
iv. $V_{oexp} = m/(\rho_w At)$, m/s
v. $\Delta P = (\rho_m - \rho_w)g\Delta H$, N/m^2
vi. $\Delta P/L = (\rho_m - \rho_w)g\Delta H/L$, N/m^3
vii. $V_{othe} = (\phi_s \Delta P €^3 D_p/1.75(1-€)\rho_w L)^{1/2}$, m/s
viii. $V_{mf\ (the)} = 0.00059g(\rho_p - \rho_w)D_p^2/\mu_w$, m/s
ix. $N_{Re} = D_{eq}V_{oexpt}\rho_w/\mu_w$
x. $f = \Delta P D_{eq}/2L\rho_w V_{oexp}^{\ 2}$

9. OBSERVATION TABLE

Sl. No.	Manometer reading, m				Amount of water collected (m), kg	Time, (t), s
	H_1, mm	H_2,mm	ΔH, mm	ΔH,m		
1.						
2.						
3.						
4.						
5.						
6.						

10. SAMPLE CALCULATIONS

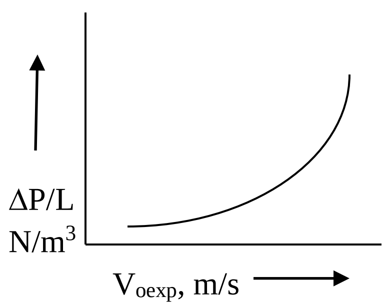
11. CALCULATION TABLE

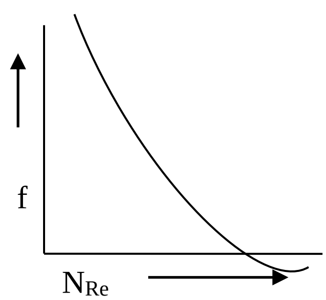
Sl. No.	ΔH m	m kg	t s	V_{oexp} m/s	N_{Re}	ΔP N/m^2	ΔP/L N/m^3	V_{othe} m/s	f
1.									
2.									
3.									
4.									
5.									
6.									

12. NATURE OF GRAPH

i. Linear portion of pressure drop curve for small flow rates and Non-linear nature during large flow rates varies the nature of Ergun's equation.

ii. From the plot determine the laminar flow and turbulent flow regimes fluid velocity the nature of graph. Observe linear nature in laminar flow and horizontal in turbulent flow region.





13. RESULTS

14. DISCUSSION ON RESULTS

15. PRACTICAL APPLICATIONS OF EXPERIMENTAL STUDY

16. VIVA QUESTIONS

i. How fluid flows through packed bed?
ii. Define Reynolds number for packed bed flow?
iii. Why pressure drop in packed bed are more than in pipe flow?
iv. What is sphericity of a particle?
v. What is equivalent diameter of a particle?
vi. What is porosity or voidage?
vii. What is superficial velocity?

17. REFERENCE

i. McCabe, W.L., *et.al.*, **"Unit Operations in Chemical Engineering"**, 5^{th} edn., McGraw Hill, New York 1993.
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EXPERIMENT NO. 04

FLOW THROUGH FLUIDIZED BED

1. AIM AND OBJECTIVE

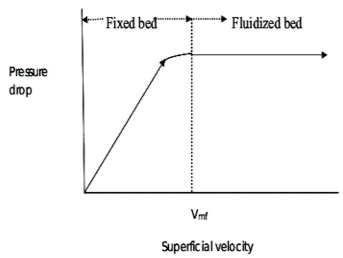
i. To study the basic principles, practical applications of solids by liquids.
ii. To discuss operation and working of fluidized bed.
iii. To verify pressure drop calculation for flow of a single in compressible fluid through bed of solids spherical material.
iv. To study the nature of expansion of the fluidized bed and determine minimum fluidization velocity of the fluid.
v. Compare with the theoretical values.

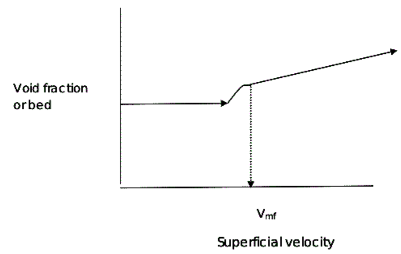
2. BACKGROUND INFORMATION AND THEORY

When a liquid or a gas is passed at very low velocity up through a bed of solid particles, the particles do not move, and the pressure drop is given by the Ergun equation. If the fluid velocity is steadily increased, the pressure drop and the drag on individual particles increase, and eventually the particles start to move and become suspended in the fluid. The terms “fluidization” and “fluidized bed” are used to describe the condition of fully suspended particles, since the suspension behaves like a dense fluid.

Fluidized beds are used extensively in the chemical process industries, particularly for the cracking of high-molecular-weight petroleum fractions. Such beds inherently possess excellent heat transfer and mixing characteristics. These are devices in which a large surface area of contact between a liquid and a gas, or a solid and a gas or liquid is obtained for achieving rapid mass and heat transfer and for chemical reactions. The fluidized bed is one of the best known contacting methods used in the processing industry, for instance in oil refinery plants. Among its chief advantages are that the particles are well mixed leading to low temperature gradients, they are suitable for both small and large scale operations and they allow continuous processing. There are many well established operations that utilize this technology, including cracking and reforming of hydrocarbons, coal carbonization and gasification, ore roasting, Fisher-Tropsch synthesis, coking, aluminum production, melamine production, and coating preparations. Nowadays, you will find fluidized beds used in catalyst regeneration, solid-gas reactors, combustion of coal, roasting of ores, drying, and gas adsorption operations The application of fluidization is also well recognized in nuclear engineering as a unit operation for example, in uranium extraction, nuclear fuel fabrication, reprocessing of fuel and waste disposal.

When a fluid is admitted at the bottom of a packed bed of solids at a low flow rate, it passes upward through bed without causing any particle motion. If the particles are quite small, flow in the channels between the particles will be laminar and the pressure drop across the bed will be proportional to the superficial velocity Vo and for turbulent situations, pressure drop across the bed increase nonlinearly with the increase in the superficial velocity. As the velocity is gradually increased, the pressure drop increases, but particles do not move and the bed height remains the same. At a certain velocity, the pressure drop across the bed counterbalances the force of gravity on the particles or the weight of the bed, and any other further increase in velocity causes the particles to move and the true fluidization begins. For a high enough fluid velocity, the friction force is large enough to lift the particles. This represents the onset of fluidization Once the bed is fluidized pressure drop across the bed remains constant, but the bed height continues to increase with increasing flow.





Minimum fluidization velocity: To better understand fluidization of a particle bed, it is necessary to determine what range of flow rates allow fluidization, and also, what flow rates will begin to carry the particles out the top of the particle chamber. It is necessary to determine a minimum flow rate allowing the particles to become fluidized, the minimum fluidization velocity (Vmf). This is the minimum superficial fluid velocity required for the fluidization to occur. It can be obtained by setting the pressure drop across the bed equal to the weight of the bed per unit area of cross section, allowing for the buoyant force of the displaced fluid: $\Delta P = g(1-\epsilon)(\rho_p - \rho)L$ At incipient fluidization, ϵ is the minimum void fraction $\Delta P = g(1-\epsilon)(\rho_p - \rho)L$ Erguns equation for pressure drop in packed beds can be applied to the point of incipient fluidization and minimum fluidization velocity can be obtained by solving the resultant quadratic equation.

The Ergun equation can be used to describe the drag exerted on a particle bed by the fluid flow. The Ergun equation is

$$f_p = \frac{150(1-\epsilon)}{\frac{\phi_s D_p V_0 \rho}{\mu}} + 1.75$$

f_p is the friction factor for a packed bed called as modified friction factor.

Where

$$f_p = \frac{\Delta P \phi_s D_p \epsilon^3}{\rho V_0^2 L(1-\epsilon)}$$

With ΔP=the pressure drop
L= the height of the bed
μ=the fluid viscosity
ϵ=void fraction
V_0 = the fluid superficial velocity
D_p =the particle diameter
ρ= the density of the fluid
φ_s = sphericity of the particle.
By rearranging and then setting

$$\Delta P = g(1-\epsilon)(\rho_p - \rho)L$$

The Ergun equation at the point of incipient fluidization is

$$\frac{\Delta P_B}{L_{mf}} \cdot \frac{\varphi_s D_p}{\rho V_{mf}^2} \frac{\epsilon_{mf}^3}{(1-\epsilon_{mf})} = \frac{150(1-\epsilon_{mf})}{\frac{\varphi_s V_{mf} D_p \rho}{\mu}} + 1.75$$

Where,
ϵ_{mf}=Minimum void fraction (before fluidization)
V_{mf} = Minimum fluidization velocity
The above equation is a quadratic.

Types of fluidization

The equations derived for minimum fluidization velocity apply to liquids as well as to gases, but beyond this velocity, the appearance of beds fluidized with liquids or gases are often quite different. Liquid fluidized beds usually exhibit “particulate fluidization” and the gas fluidized beds exhibit bubbling fluidization (Refer Unit Operations of Chemical Engineering by McCabe and Smith.

3. APPARTUS USED

i. Fluidized bed column
ii. Spherical particles
iii. Manometer
iv. Stop clock
v. Meter scale
vi. Centrifugal pump

4. EXPERIMENTAL SET UP

5. EXPERIMENTAL PROCEDURE

i. Connect the manometer at the locations provided.
ii. Switch on the pump with the by-pass valve opened fully.
iii. Initially adjust the flow rate very slowly through the bed
iv. Remove all the air entrapped in the bed and the manometer.
v. Switch off the pump and determine the voidage of the bed by noting down amount of water collected in the bed.
vi. Start the pump and adjust the flow rate at lowest level
vii. Note down the corresponding manometeric reading.
viii. Note down the amount of water collected from the bed and time required to collect the water.
ix. Slowly increase the flow rate by flow regulating valve such that spherical particle just start moving upward and repeat the steps vii and viii for at least 6 readings.
x. Calculate V_{oexp} and N_{Re} for the various flow rates.
xi. Plot a graph of pressure drop per unit length of bed v/s V_{oexp}.

6. DATA

i. Height of the packed bed, $L = 440X10^{-3}$, m
ii. Diameter of the particle, $D_p = 14X10^{-3}$, m
iii. Diameter of the tower, $D_t = 75X10^{-3}$, m
iv. Density of packing material, $\rho_p = 1.8$
v. Bed porosity, € = 0.4
vi. Density of water, $\rho_w = 1000$ kg/m^3
vii. Viscosity of water, $\mu_w = 0.76x10^{-3}$kg/m-s
viii. Density of Mercury, $\rho_m = 13600$ kg/m^3
ix. Acceleration due to gravity, g=9.81 m/s^2

7. NOTATIONS

i. H_1 – Height of mercury in right limb, m
ii. H_2 – Height of mercury in left limb, m
iii. ΔH – Manometer liquid difference, m
iv. m – Amount of water collected, kg
v. t – Time taken to collect water, s
vi A– cross-sectional area of empty tower, m^2
vii V_{oexpt} – Fluid superficial velocity based on chamber cross section, m/s
viii N_{Re} – Reynolds number, Dimensionless
ix. ΔP – Pressure drop, N/m^2
x. V_{othe} – theoretical fluidization velocity, m/s
xi. $V_{mf\ (the)}$ – minimum fluidization velocity, m/s

8. FORMULAE

i. $\Delta H = H_1 + H_2$, m

ii. $A = \pi D_t^2/4$, m^2

iii. $V_{0exp} = m/\rho_w At$, m/s

iv. $D_{eq} = 2D_p\phi_s€/3(1-€)$, m

v. $\Delta P – (\rho_m - \rho_w)g\Delta H$, N/m^2

vi. $\Delta P/L = (\rho_m - \rho_w)g\Delta H/L$, N/m^3

vii. $N_{Re} = D_{eq}V_{oexpt}\rho_w/\mu_w$

viii. $V_{othe} = (\Delta P€^3 D_{eq}/1.75(1-€)\ \rho_w L)^{1/2}$, m/s

ix. $V_{mf\ (the)} = 0.00059g(\rho_p - \rho_w)D_p^2/\mu_w$, m/s

9. OBSERVATION TABLE

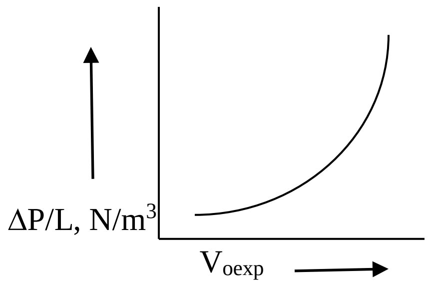
Sl. No.	Manometer reading, m				Amount of water collected (W), kg	Time, s
	H_1, mm	H_2,mm	ΔH, mm	ΔH, m		
1.						
2.						
3.						
4.						
5.						

10. SAMPLE CALCULATIONS

11. CALCULATION TABLE

Sl. No.	ΔH m	W kg	t s	V_{oexpt} m/s	N_{Re}	ΔP N/m^2	ΔP/L N/m^3	V_{othe} m/s	$V_{mf\ (the)}$ m/s

12. NATURE OF GRAPH



13. RESULTS

14. DISCUSSION ON RESULTS

15. PRACTICAL APPLICATIONS OF EXPERIMENTAL STUDY

16. VIVA QUESTIONS

i. Explain fluidization and fluidized bed.
ii. What happens to pressure drop in fluidized beds?
iii. What is minimum fluidization velocity?
iv. What are the forces acting on the particles in fluidized beds?
v. What is bubbling fluidization?
vi. What are the types of fluidization?

17. REFERENCE

i. McCabe, W.L., *et.al.*, "Unit Operations in Chemical Engineering", 5th edn., McGraw Hill, New York 1993.
ii. Chemical Engineers Handbook, Perry & Green, 8th edn, McGraw Hill, 1997.
iii. Badger W.L. and Banchero J.T., "Introduction to Chemical Engineering", Tata McGraw Hill, New York 1997
iv. Coulson J.H. and Richardson J.F., "Chemical Engineering", Vol-I, 5th edn., Asian Books (p) Ltd., New Delhi, 1998.

EXPERIMENT NO. 05

STUDY OF CHARETRISTICS CENTRIFUGAL PUMP

1. AIM AND OBJECTIVE

i. To study the principles of centrifugal pump and its characteristics.
ii. To discuss the operations and working of centrifugal pump.
iii. To conduct the centrifugal pump experiment with water at constant speed.
iv. To determine the flow rate at different discharge pressure and calculate power consumed.
v. Plot the characteristic curve at constant speed.

2. BACKGROUND INFORMATION AND THEORY

3. APPARTUS REQUIRED

i. Centrifugal pump
ii. Tachometer
iii. Energy meter
iv. Stop watch

4. EXPERIMENTAL SET UP

5. EXPERIMENTAL PROCEDURE

i. Prime the pump with water close the valve after priming, open the lock P. Ensure air is removed and only water enters. Close P.
ii. Start the motor.
iii. For constant speed take at least 6 readings by varying the head from the maximum shut off to minimum where gate valve is fully open.
iv. Record the following after the constant speed is set 1440 RPM.
   a. The pressure gauge reading
   b. The vacuum pressure gauge readings
   c. Time for 10 revolutions of the disk in the energy meter using stop watch
   d. Time for 20 cm rise of water level in the measuring tank using stop watch

6. DATA

i. Length of the tank, L = m
ii. Breadth of the tank, B = m
iii. Difference of the level between pressure and vacuum gauge = 42.5 cm
iv. Speed of the pump =1440 RPM
v. Number of revolution in energy meter = RPM

7. NOTATIONS

i. G – Pressure gauge, Kpa
ii. V – Vacuum gauge, Kpa
iii. X – Vertical difference of the level between pressure and vacuum gauge, cm
iv. ΔP – pressure drop or pressure difference , Kpa
v. H – pressure head, m of water
vi. Δh – difference in head, m
vii. Z – potential head, m
viii. V_w – volume of water collected in tank, m^3
ix. t – Time for rise in water level in tank, sec
x. Q – volumetric flow rate of the water, m^3/s
xi. T – time taken for 10 revolutions, sec
xii. N – speed in RPM
xiii. I/P – Input power, KW
xiv. O/P – Out power, KW
xv. η – Efficiency in percentage
xvi. n – energy meter constant = 240

8. FORMULAE

i. Area of the tank , A = LB, m^2
ii. Volume of the tank , V_w = Ah, m^3

iii. Volumetric flow rate of the water, $Q = V_w/ t$, m^3/s
iv. Input Power, I/P = 3600 x 10/ NT, KW
v. Total head, H = G + V + X
vi. X = G-V
vii. Output Power, O/P = 9810QH/1000, KW
viii. Efficiency, η = Output power/Input power *100

9. OBSERVATION TABLE

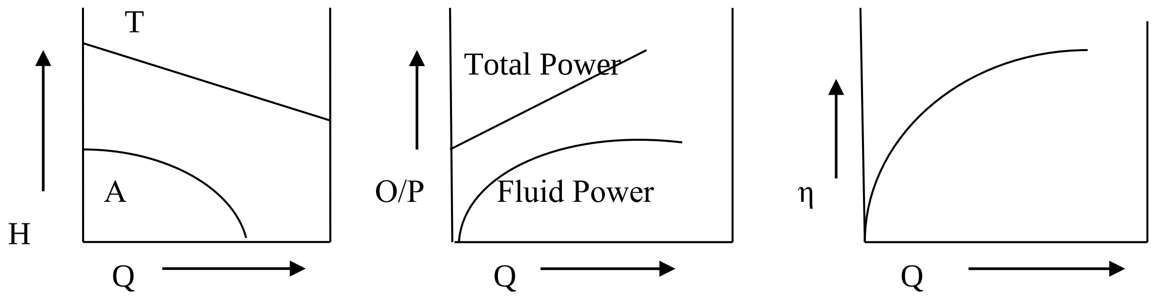
Sl. No.	Vacuum gauge (V) Kg/cm^2	Pressure gauge (G) Kg/cm^2	Time for 10 revolutions (T), cm	Time for 20 cm rise in water level (t), cm	Speed(N) RPM
1.					
2.					
3.					
4.					
5.					

10. SAMPLE CALCULATIONS

11. CALCULATION TABLE

Sl. No.	X m	H = G + V + X m of water	Q m^3/s	I/P KW	O/P KW	η %

12. NATURE OF GRAPH



13. RESULTS

14. DISCUSSION ON RESULTS

15. PRACTICAL APPLICATIONS OF EXPERIMENTAL STUDY

16. VIVA QUESTIONS

i. What is positive and negative displacement Pumps?
ii. What is the principle of centrifugal pump?
iii. What are the advantages of disadvantages of centrifugal pump?

17. REFERENCE

i. McCabe, W.L., *et.al.*, "Unit Operations in Chemical Engineering", 5th edn., McGraw Hill, New York 1993.
ii. Chemical Engineers Handbook, Perry & Green, 8th edn, McGraw Hill, 1997.
iii. Badger W.L. and Banchero J.T., "Introduction to Chemical Engineering", Tata McGraw Hill, New York 1997
iv. Coulson J.H. and Richardson J.F., "Chemical Engineering", Vol-I, 5th edn., Asian Books (p) Ltd., New Delhi, 1998.
v. Dr R K Bansal., "A Text Book of Fluid Mechanics" 1st edn., Laxmi Publications (P) Ltd., New Delhi, 2005.

EXPERIMENT NO. 06

FLOW THROUGH PIPE FITTINGS

1. AIM AND OBJECTIVE

i. To study the various types of pipe fittings and symbols used in process industries.
ii. To study the pressure drop calculation in some types of pipe fittings.
iii. To define fittings coefficient or equivalent length of pipe fittings.
iv. To conduct a laboratory experiment for determination of loss coefficient of
   a) Sudden expansion b) Sudden contraction c)Bend d) Elbow
v. To plot the graph of pressure drop vs. velocity head for each type of fittings.

2. BACKGROUND INFORMATION AND THEORY

One of the most common problems in fluid mechanics is the estimation of pressure loss. Pipe losses in a piping system result from a number of system characteristics, which include among others; pipe friction, changes in direction of flow, obstructions in flow path, and sudden or gradual changes in the cross-section and shape of flow path.

Whenever the velocity of a fluid is changed, either in direction or magnitude, by a change in the direction or size of the conduit, friction additional to the skin friction from flow through the straight pipe is generated. Such friction includes form friction resulting from vortices which develop when the normal streamlines are disturbed and when boundary-layer separation occurs. The form friction is due to the obstructions present in the line of flow, it may be due to a bend or a control valve or anything which changes the course of motion of the flowing fluid.

Fittings and valves also disturb the normal flow lines and cause friction. In short, the friction loss from the fittings may be greater than that from the straight pipe. As in straight pipe, velocity increases through valves and fittings at the expense of head loss. This can be expressed by equation similar to Equation:

$$h_{fe} = K_e \frac{V^2}{2g}$$

Where,

V is the average velocity of the pipe leading to fitting.

K_e is called the resistance coefficient and is defined as the number of velocity heads lost due to the valve or fitting. It is a measure of the following pressure losses in a valve or fitting:

- Pipe friction in the inlet and outlet straight portions of the valve or fitting
- Changes in direction of flow path
- Obstructions in the flow path
- Sudden or gradual changes in the cross-section and shape of the flow path

Pipe friction in the inlet and outlet straight portions of the valve or fitting is very small when compared to the other three. Since friction factor and Reynolds Number are mainly related to pipe friction, K_e can be considered to be independent of both friction factor and Reynolds

Number. Therefore, K_e is treated as a constant for any given valve or fitting under all flow conditions, including laminar flow. Indeed, experiments showed that for a given valve or fitting type, the tendency is for K_e to vary only with valve or fitting size.

A pressure loss in fittings is usually represented by equivalent length (L_{eq}). It is the length of a straight pipe that offers same resistance to flow as that offered by the fitting. The ratio L/D is equivalent length in pipe diameters of straight pipe that will cause the same pressure drop or head loss as the valve or fitting under the same flow conditions. The ratio L_{eq}/D is equivalent length in pipe diameters of straight pipe that will cause the same pressure drop or head loss as the valve or fitting under the same flow conditions. Friction loss from different fittings in a pipe line must be accounted for when calculating friction losses for each section of pipe. Add the equivalent length of pipe for each fitting or valve that occurs in each section of the pipeline.

Fittings

Globe Valve

Srewed fittings

3. APPARTUS USED

i. Piping system – the pipe fittings considered are
   a)Sudden expansion b) Sudden contraction c)Bend d) Elbow
ii. Manometer
iii. Meter scale
iv. Stop watch
v. Measuring tank

4. EXPERIMENTAL SET UP

5. EXPERIMENTAL PROCEDURE

i. Ensure 75% of the sump is filled with clean water.
ii. Open the inlet valve leading to the pipe fittings and valves leading to other lines closed.
iii. Switch on the pump and remove the air bubbles trapped in the manometer tube.
iv. Set a flow rate of water through the pipe fitting by opening the main valve and throttling the bypass valve suitably using the control valve.

v. Record the level of manometer fluid in left and right limbs after a steady state is attained.
vi. Note down the time taken for 100 cm rise in water level in collection tank. (Ensure that outlet valve is closed).
vii. Increase the flow rate of water by opening the main valve and throttling the bypass valve suitably and repeat step iv and vi.
viii Repeat the procedure for different types of fittings.

6. DATA

i. Diameter of the pipe, D_1 = ……….. m D_2= ……… m
ii. Length of pipe, $L_1=L_2$ =………… m
iii. Area of the tank, A_T = Length X Breadth, m A_T…………m
iv. Density of water, $\rho_w = 1000$ kg/m^3
v. Viscosity of water, $\mu_w = 0.76X10^{-3}$kg/m-s
vi. Density of Mercury, $\rho_m = 13600$ kg/m^3
vii. Acceleration due to gravity, g=9.81 m/s^2

7. NOTATIONS

i. H_1 – Height of mercury in right limb, m
ii. H_2 – Height of mercury in left limb, m
iii. ΔH – Manometer liquid difference, m
iv. h_1 –Initial height of water level in measuring tank, m
v. h_2 –Final height of water level in measuring tank, m
vi Δh – Water level rise in measuring tank , m
vii t – Time taken for rise in water level, s
viii V_w – Volume of water collected, m^3
ix. Q – Volumetric flow rate, m^3/s
x. V- Velocity of fluid flow in pipe, m/s
xi. N_{Re} – Reynolds number, Dimensionless
xii. f – friction factor for laminar flow, $N_{Re} < 2100$
xiii. L_{eq}- Equivalent length, m
xiv. ΔP – Pressure drop, N/m^2
xv. K – Loss co-efficient

8. FORMULAE

i. $\Delta H = H_1 - H_2$, m
ii. $\Delta h = h_1 - h_2$, m
iii. $A_T = LXB$, m^2
iv. $V_w = LXBX\Delta h$, m^3
v. $Q = V_w / t$, m^3/s

vi. $V = Q/A$, m/s

vii. $N_{Re} = DV\rho/\mu$

viii. Fanning's friction factor, $f = 16/N_{Re}$, for laminar flow $N_{Re} < 2100$

$f = 0.014 + 0.125\, N_{Re}^{-0.72}$, for transition region $2100 < N_{Re} < 4000$

$f_t = 0.079\, N_{Re}^{-1/4}$,friction factor for turbulent flow $N_{Re} > 4000$

ix. $\Delta P = (\rho_m - \rho_w) g \Delta H$, N/m^2

x. Equivalent length, $L_{eq} = \Delta P 2D / 4fV^2 \rho_w$, m

xi. Kinetic head correlation, $K = \rho_w V^2/2$, kg/ms^2

9. OBSERVATION TABLE

i. BEND

Sl. No.	Manometer reading, m				Water level reading, m				Time(t) s
	H_1, cm	H_2,cm	ΔH,cm	ΔH,m	h_1,cm	h_2,cm	Δh,cm	Δh,m	
1.									
2.									
3.									
4.									
5.									

ii. ELBOW

Sl. No.	Manometer reading, m				Water level reading, m				Time(t) s
	H_1 cm	H_2,cm	ΔH,cm	ΔH,m	h_1,cm	h_2,cm	Δh,cm	Δh,m	
1.									
2.									
3.									
4.									
5.									

iii. CONTRACTION

Sl. No.	Manometer reading, m				Water level reading, m				Time(t) s
	H_1,cm	H_2,cm	ΔH,cm	ΔH,m	h_1,cm	h_2,cm	Δh,cm	Δh,m	
1.									
2.									
3.									
4.									
5.									

iii. EXPANSION

Sl. No	Manometer reading, m				Water level reading, m				Time(t), s
	H_1, cm	H_2,cm	ΔH,cm	ΔH,m	h_1,cm	h_2,cm	Δh,cm	Δh,m	
1.									
2.									
3.									
4.									
5.									

10. SAMPLE CALCULATIONS

11. CALCULATION TABLE

i. BEND

Sl. No.	ΔH m	Δh m	t s	Q m^3/s	V m/s	N_{Re}	f	ΔP N/m^2	Kinetic head $\rho_w V^2/2$	L_{eq} m
1.										
2.										
3.										
4.										
5.										

ii. ELBOW

Sl. No.	ΔH m	Δh m	t s	Q m^3/s	V m/s	N_{Re}	f	ΔP N/m^2	Kinetic head $\rho_w V^2/2$	L_{eq} m
1.										
2.										
3.										
4.										
5.										

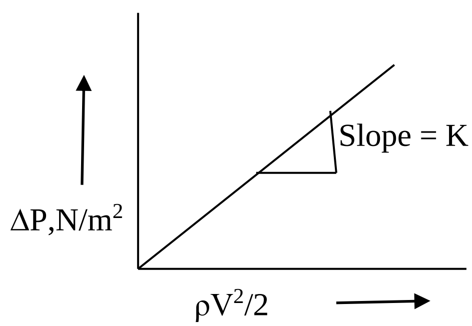
iii. CONTRACTION

Sl. No.	ΔH m	Δh m	t s	Q m^3/s	V m/s	N_{Re}	f	ΔP N/m^2	Kinetic head $\rho_w V^2/2$	L_{eq} m
1.										
2.										
3.										
4.										
5.										

iv. EXPANSION

Sl. No.	ΔH m	Δh m	t s	Q m^3/s	V m/s	N_{Re}	f	ΔP N/m^2	Kinetic head $\rho_w V^2/2$	L_{eq} m
1.										
2.										
3.										
4.										
5.										
6.										

12. NATURE OF GRAPH



13. RESULTS

Sl. No.	Fitting	K from graph
1	Bend	
2	Elbow	
3	Sudden contraction	
4	Sudden expansion	

14. DISCUSSION ON RESULTS

15. PRACTICAL APPLICATIONS OF EXPERIMENTAL STUDY

16. VIVA QUESTIONS

i. Explain the term pipe fitting?
ii. What is friction factor?
iii. What is laminar, turbulent flow?
iv. How do you minimize expansion and contraction losses?
v. What are the effects of fittings and valves in pipe lines?
vi. What are the uses of valves?
vii. Mention different types of valves used in industry?

17. REFERENCE

i. McCabe, W.L., *et.al.*, “Unit Operations in Chemical Engineering”, 5thedn., McGraw Hill, New York 1993.
ii. Chemical Engineers Handbook, Perry & Green, 8th edn, McGraw Hill, 1997.
iii. Badger W.L. and Banchero J.T., “Introduction to Chemical Engineering”, Tata McGraw Hill, New York 1997
iv. Coulson J.H. and Richardson J.F., “Chemical Engineering”, Vol-I, 5thedn., Asian Books (p) Ltd., New Delhi, 1998.

EXPERIMENT NO. 07
FLOW THROUGH COILS

1. AIM AND OBJECTIVE

i. To study the principles of fluid flow through a coil.
ii. To carry out an experiment using given coil in the laboratory.
iii. To obtain equivalent length of the coil.
iv. To find friction factor of coil.
v. To obtain a graphical correlation between the ratio L_{Eq} /L and Dean's number, friction factor.

2. BACKGROUND INFORMATION AND THEORY

Coiled pipes of helical shape have an extensive application in various industries: chemical, biomedical, mechanical, agricultural, and among others. They are applied in a wide range of processes: water supply, drainage, separation, and reaction. There are several literatures that have made researches on the internal flow of helical pipe. Eustice1 first made the experiment by injecting ink into coiled pipe filled with water to observe the centrifugal force induced secondary flow, which is the nature of curved flow. Later Dean2 provided the solution to the flow in curved pipes through theoretical analysis and gave an original definition of Dean effect associated with curvature. Then, this effect was developed to be a non-dimensional quantity to characterize the magnitude of secondary flow.

$De=N_{Re}\,(d_c/D_c)^{1/2}$ where N_{Re} is the Reynolds number, d_c is the pipe diameter, and D_c is the pipe bending radius. Then, several theoretical had been made to solve the equations of pipe fluid motion.

3. APPARTUS USED

i. Copper Coil
ii. Manometer
iii. Pump
iv. Stop watch
v. Bucket
vi. Scale
vii. Control valves

4. EXPERIMENTAL SET UP

5. EXPERIMENTAL PROCEDURE

i. Connect the manometer at the points provided.
ii. Switch on the pump with the by-pass valve opened fully.
iii. Open the coil inlet valve slowly and water will flow directly into the coil.
iv. Remove all the air entrapped in the system by opening the valves on the top of manometer simultaneously and ensure that all air bubbles are removed.
v. After adjusting the flow rate, wait till steady state is reached.
vi. Note down the corresponding manometer reading to measure pressure drop.
vii. Note down the amount of water collected and time required to collect the water.
viii. Slowly increase the flow rate and repeat step vii to vii for at least 6 readings.

6. DATA

i. Diameter of the coil 1(inner), D_{c1} = 0.16 m
ii. Diameter of the coil 2(outer), D_{c2} = 0.28 m
iii. Coil pipe diameter 1(inner), d_{c1} = 0.0125 m
iv. Coil pipe diameter 2(outer), d_{c2} = 0.0125 m
v. Number of turns of coil 1 = 8
vi. Number of turns of coil 2 = 4
vii. Density of water, ρ_w = 1000 kg/m^3
viii. Density of Mercury, ρ_m = 13600 kg/m^3
ix. Viscosity of water, μw= $0.76x10^{-3}$kg/m-s
x. Acceleration due to gravity, g=9.81 m/s^2
xi. Length of coil 1(inner) L_{c1} = 4.02 m
xii. Length of coil 2 (outer) L_{c2} = 3.51 m

7. NOTATIONS

i. H_1 – Height of mercury in right limb, m
ii. H_2 – Height of mercury in left limb, m
iii. ΔH – Manometer liquid difference, m
iv. m – Amount of water collected, kg
vi. t – Time taken to collect water, s
vii. A– cross-sectional area of Pipe, m^2
viii. Q – Volumetric flow rate, m^3/s
ix. V- Velocity of fluid flow in pipe, m/s
x. N_{Re} – Reynolds number, Dimensionless
xi. ΔP – Overall Pressure drop, N/m^2
xii. $\Delta P/L$, $(\Delta P)_L$ – Pressure drop per unit length of straight same volumetric flow rate through coil, N/m^3
xiii. f_1 – friction factor for coil calculated using Fanning's equation
xiv. D_e – Dean's Number
xv. f_{coil} = friction factor for coil calculated empirically

8. FORMULAE

i. $\Delta H = H_1 + H_2$, m

ii. $Q = m/\rho_w t$, m^3/s

iii. $A = \pi d_c{}^2/4$, m^2

iv. $V = Q/A$, m/s

v. $N_{Re} = d_c V \rho_w / \mu_w$

vi. Dean's Number, $D_e = N_{Re}(d_c/ D_c)^{1/2}$

vii. $\Delta P_{coil} = (\rho_m - \rho_w) g \Delta H$, N/m^2

viii. Friction factor ,$f = 0.079 N_{Re}{}^{-1/4}$,friction factor for turbulent flow, $N_{Re} > 4000$

$f = 16/ N_{Re}$, for laminar flow, $N_{Re} < 2100$

ix. Fanning's equation, $\Delta P = (2f L\rho_w V^2)/ d_c$,N/m^3

Fanning's equation, $\Delta P/L = (\Delta P)_L = (2f \rho_w V^2)/ d_c$

x. Equivalent length of coil, $L_{eq} = \Delta P_{coil}/(\Delta P)_L$, m

xi. From empirical correlation, $f_{coil} = 0.08 N_{Re}{}^{-1/4} + 0.01(d_c/ D_c)^{1/2}$

xii. Friction factor from Fanning's equation, $f_1 = d_c(\Delta P)_L/2L \rho_w V^2$

9. OBSERVATION TABLE

i. For Inner Coil

Sl. No.	Manometer reading, m				Amount of water collected (m), kg	Time, (t), s
	H_1, mm	H_2,mm	ΔH, mm	ΔH, m		
1.						
2.						
3.						
4.						
5.						

ii. For Outer Coil

Sl. No.	Manometer reading, m				Amount of water collected (m), kg	Time, (t), s
	H_1, mm	H_2,mm	ΔH, mm	ΔH,m		
1.						
2.						
3.						
4.						
5.						

10. SAMPLE CALCULATIONS

11. CALCULATION TABLE

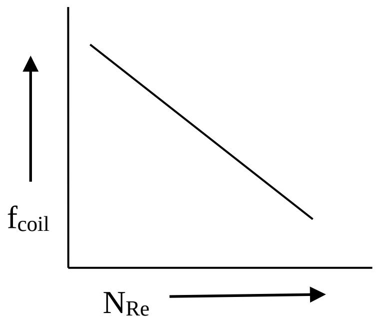
i. For Inner Coil

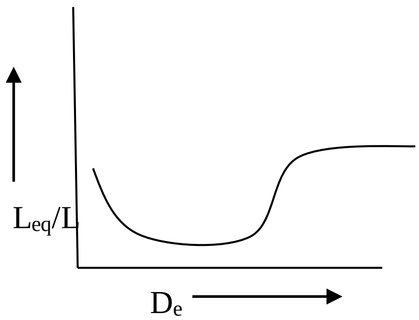
Sl. No.	ΔH m	m kg	t s	Q m^3/s	u m/s	N_{Re}	D_e	ΔP_{coil} N/m^2	$\Delta P_{coil}/L$ N/m^3	L_{eq} m	L_{eq}/L	f_{coil}	f_1
1.													
2.													
3.													
4.													
5.													

ii. For Outer Coil

Sl. No.	ΔH m	m kg	t s	Q m^3/s	u m/s	N_{Re}	D_e	ΔP_{coil} N/m^2	$\Delta P_{coil}/L$ N/m^3	L_{eq} m	L_{eq}/L	f_{coil}	f_1
1.													
2.													
3.													
4.													
5.													
6.													

12. NATURE OF GRAPH





13. RESULTS

14. DISCUSSION ON RESULTS

15. PRACTICAL APPLICATIONS OF EXPERIMENTAL STUDY

16. VIVA QUESTIONS

i. What are boundary layers?
ii. Explain Newtonian and Non-Newtonian fluids.
iii. Explain laminar and turbulent flow.
iv. What are Reynold's number and Dean's number?
v. What is Fanning's equation?
vi. Explain friction factor chart, give the relation between friction factor and Reynold's number
vii. What is equivalent length of the coil?

17. REFERENCE

i. McCabe, W.L., *et.al.*, "Unit Operations in Chemical Engineering", 5^{th} edn., McGraw Hill, New York 1993.
ii. Chemical Engineers Handbook, Perry & Green, 8^{th} edn, McGraw Hill, 1997.
iii. Badger W.L. and Banchero J.T., "Introduction to Chemical Engineering", Tata McGraw Hill, New York 1997
iv. Coulson J.H. and Richardson J.F., "Chemical Engineering", Vol-I, 5^{th} edn., Asian Books (p) Ltd., New Delhi, 1998.

EXPERIMENT NO. 08

FLOW THROUGH NON CIRCULAR SECTION

1. AIM AND OBJECTIVE

i. To study the flow nature of the fluid in the non circular section.
ii. To verify the correlation factor for the non circular.
iii. To plot the friction factor curves for the non circular sections.
iv. To define the equivalent diameter for a) Triangular b) Square c) Annular non circular conduits.
v. To compare calculated friction factor with the experimental values.

2. BACKGROUND INFORMATION AND THEORY

For turbulent flow in a duct of non-circular cross-section, the hydraulic mean diameter may be used in place of the pipe diameter and the formulae for circular pipes can then be applied without introducing a large error. This method of approach is entirely empirical.
The hydraulic mean diameter D_H is defined as four times the hydraulic mean radius r_H. Hydraulic mean radius is defined as the flow cross-sectional area divided by the wetted perimeter: Some examples are given. For circular pipe:

$D_H = 4(p/4)D^2 / (pD) = D$

For an annulus of outer dia D_o and inner dia D_i :

$D_H = 4 ((pD_o^2 /4) - (pD_i^2 /4)) / (p(D_o + D_i)) = (D_o^2 - D_i^2) / (D_o + D_i) = D_o - D_i$

For a duct of rectangular cross-section D_a by D_b :

$D_H = 4 D_a D_b / (2(D_a + D_b) = 2D_aD_b / (D_a + D_b)$

For a duct of square cross-section of size D_a :

$D_H = 4 D_a^2 / (4D_a) = D_a$

For laminar flow this method is not applicable, and exact expressions relating the pressure drop to the velocity can be obtained for ducts of certain shapes only.

3. APPARTUS

i. Non circular section viz. Triangular, Square, Annulus
ii. Manometer
iii. Stopwatch
iv. Weighing Balance
v. Bucket

4. EXPERIMENTAL SET UP

5. EXPERIMENTAL PROCEDURE

i. Connect a non circular conduit.
ii. Connect the manometer to manometer tapping.
iii. Operate the valve for desired flow.
iv. Note down the corresponding manometeric reading.
v. Record the time for the amount of water in known interval of height.
vi. Repeat the steps from iii to v for at least 6 readings.
vii. Switch over to other sections and repeat this procedure.
viii. Calculate $D_{eq,}$ V, N_{Re} for various sections at various flow rates.

6. DATA

i. Triangular section: Width , B = 0.025 m Length, L = 2.7 m
ii. Square section : Width, B = 0.025m Length, L = 2.4 m
iii. Annulus: Inner diameter of outer pipe, d_1= 0.032 m
Outer diameter of inner pipe, d_2= 0.013 m
Length of pipe, L = 2.4 m
iv. Density of water, ρ_w = 1000 kg/m^3
v. Density of Mercury, ρ_m = 13600 kg/m^3
vi. Viscosity of water, μ_w= 0.76×10^{-3}kg/m-s

7. NOTATIONS

i. H_1 – Height of mercury in right limb, m
ii. H_2 – Height of mercury in left limb, m
iii. ΔH – Manometer liquid difference, m
iv. m – Amount of water collected, kg
v. t – Time taken to collect water, s
vi. V – velocity of fluid, m/s
vii. L – Length between manometer tapings, m
viii. A – Cross-sectional area of non circular section, m^2
ix. D_{eq}- Equivalent diameter, m
x. $f_{(exp)}$- Experimental friction factor, Dimensionless
xi. $f_{(cal)}$- Calculated friction factor, Dimensionless
xii. N_{Re} – Reynolds number, Dimensionless
xiii. ΔP – Pressure drop, N/m^2

8. FORMULAE

i. $\Delta H = H_1 + H_2$, m
ii. $Q = m/(\rho_w t)$, m/s
iii. $V = m/(\rho_w A t) = Q/A$, m/s

iv. $A_{(Tri)} = 1/2XBXh$, m^2

$A_{(sq)} = B^2$, m^2

$A_{(Anu)} = \pi/4(d_1^2 - d_2^2)$, m^2

v. $D_{Eq(Tri)} = 2/3h$, m

$D_{Eq(sq)} = W$, m

$D_{Eq(Anu)} = d_2 - d_1$, m

vi. $N_{Re} = D_{Eq}V\ \rho_w/\ \mu_w$

vii. $\Delta P = (\rho_m - \rho_w)g\Delta H$, N/m^2

viii. $f_{exp(Tri)} = 0.079\ N_{Re}^{-1/4}$

$f_{exp(sq)} = 0.079\ N_{Re}^{-1/4}$

$f_{exp(Anu)} = 0.076\ N_{Re}^{-1/5}$

ix. $f_{cal} = D_{Eq}\ \Delta P/2\ \rho_w v^2 L$

9. OBSERVATION TABLE

i. Triangular cross sectional conduct

Sl. No.	Manometer reading, m				Amount of water collected (m), kg	Time, (t), s
	H_1, mm	H_2,mm	ΔH, mm	ΔH, m		
1.						
2.						
3.						
4.						

ii. Square cross sectional conduct

Sl. No.	Manometer reading, m				Amount of water collected (m), kg	Time, (t), s
	H_1, mm	H_2,mm	ΔH, mm	ΔH, m		
1.						
2.						
3.						
4.						

iii. Annular cross sectional conduct

Sl. No.	Manometer reading, m				Amount of water collected (m), kg	Time, (t), s
	H_1,mm	H_2,mm	ΔH, mm	ΔH,m		
1.						
2.						
3.						
4.						
5.						

10. SAMPLE CALCULATIONS

11. CALCULATION TABLE

i. Triangular cross sectional conduct

Sl. No	ΔH m	m kg	t s	Q m^3/s	V m/s	N_{Re}	ΔP N/m^2	f_{exp}	f_{cal}
1.									
2.									
3.									
4.									

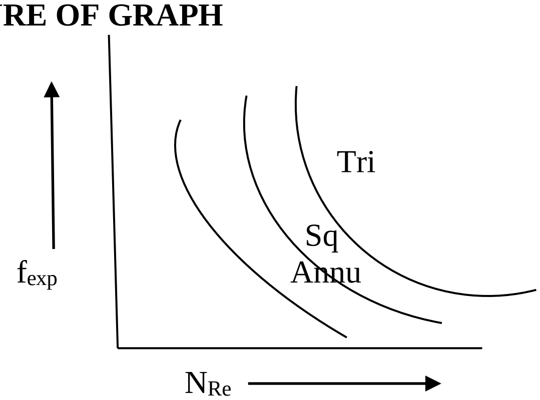
ii. Square cross sectional conduct

Sl. No	ΔH m	m kg	t s	Q m^3/s	V m/s	N_{Re}	ΔP N/m^2	f_{exp}	f_{cal}
1.									
2.									
3.									
4.									

iii. Annular cross sectional conduct

Sl. No	ΔH m	m kg	t s	Q m^3/s	V m/s	N_{Re}	ΔP N/m^2	f_{exp}	f_{cal}
1.									
2.									
3.									
4.									

12. NATURE OF GRAPH



13. RESULTS

14. DISCUSSION ON RESULTS

15. PRACTICAL APPLICATIONS OF EXPERIMENTAL STUDY

16. VIVA QUESTIONS

i. What are the different types of non circular sections used in industry
ii. Define equivalent diameter.
iii. What is hydraulic radius?
iv. Write velocity distribution in triangular and square cross sectional conduits.

17. REFERENCE

i. McCabe, W.L., *et.al.*, "Unit Operations in Chemical Engineering", 5th edn., McGraw Hill, New York 1993.
ii. Chemical Engineers Handbook, Perry & Green, 8th edn, McGraw Hill, 1997.
iii. Badger W.L. and Banchero J.T., "Introduction to Chemical Engineering", Tata McGraw Hill, New York 1997
iv. Coulson J.H. and Richardson J.F., "Chemical Engineering", Vol-I, 5th edn., Asian Books (p) Ltd., New Delhi, 1998.

EXPERIMENT NO. 09

UNSTEADY STATE FLOW

1. AIM AND OBJECTIVE

i. To study unsteady state flow.
ii. To plot a graph of time vs. square root of liquid height
iii. To conduct C_d of the tank.

2. BACKGROUND INFORMATION AND THEORY

3. APPARTUS REQUIRED

i. Tank
ii. Stop watch
iii. Meter scale

4. EXPERIMENTAL SET UP

5. EXPERIMENTAL PROCEDURE

i. Open the inlet valve and close the outlet valve.
ii. Allow the water to flow in to the tank and collect water up to 1m height.
iii. Measure c/s area of the tank and orifice.
iv. Open the outlet valve and remove the plug.
v. Start the stop watch and go on noting the time for every 10cm drop in water level until water is drained off.
vi. Repeat the steps i to v for 2 more consequent readings.
vii. Tabulate the results and find the average time and $\sqrt{H}$.

6. DATA

i. Area of the tank, A =Length x Breadth, m^2
ii. Area of the orifice, $a = \pi d^2 / 4$, m^2
iii. Length of the tank, L = m
iv. Breadth of the tank, B = m
v. Diameter of orifice, d =
vi. Acceleration due to gravity, $g = 9.81\ m/s^2$

7. NOTATIONS

i. A – Cross sectional area of the tank, m^2
ii. a - Cross sectional area of the orifice, m^2
iii. H_1 – Height of liquid level at time t = 0, m
iv. H_2 - Height of liquid level at time $t = t_s$, m
v. t – Time required to empty the tank, s
vi. C_d –Co-efficient of discharge

8. FORMULAE

i. $t = 2A(H_1^{1/2} – H_2^{1/2}) / C_d\, a\sqrt{2g}$

Plot t_{avg} v/s. $\sqrt{H}$

Slope , $m = 2A/ C_d\, a\sqrt{2g}$

$C_d = 2A/ m\, a\sqrt{2g}$

9. OBSERVATION TABLE

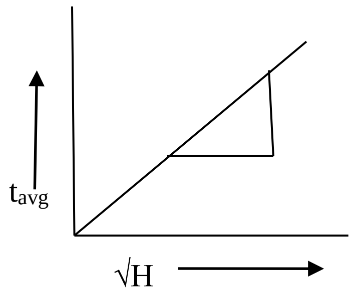
Sl. No.	Height(H), cm	t_1, Sec	t_2, Sec	t_{avg} ,Sec
1.				
2.				
3.				
4.				
5.				

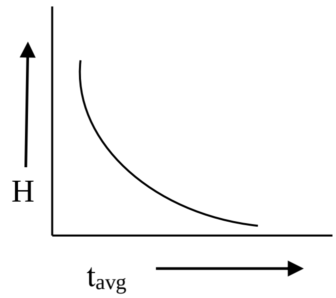
10. SAMPLE CALCULATIONS

11. CALCULATION TABLE

Sl. No.	Height(H) cm	t_1 Sec	t_2 Sec	t_{avg} Sec	$\sqrt{H}$	C_d
1.						From graph
2.						
3.						
4.						
5.						

12. NATURE OF GRAPH





13. RESULTS

14. DISCUSSION ON RESULTS

15. PRACTICAL APPLICATIONS OF EXPERIMENTAL STUDY

16. VIVA QUESTIONS

i. What is steady state and unsteady state condition?
ii. How do u find the coefficient of discharge?

17. REFERENCE

i. McCabe, W.L., *et.al.*, "Unit Operations in Chemical Engineering", 5th edn., McGraw Hill, New York 1993.
ii. Chemical Engineers Handbook, Perry & Green, 8th edn, McGraw Hill, 1997.
iii. Dr R K Bansal., "A Text Book of Fluid Mechanics" 1st edn., Laxmi Publications (P) Ltd., New Delhi, 2005.

EXPERIMENT NO. 10

NOTCHES AND WEIRS

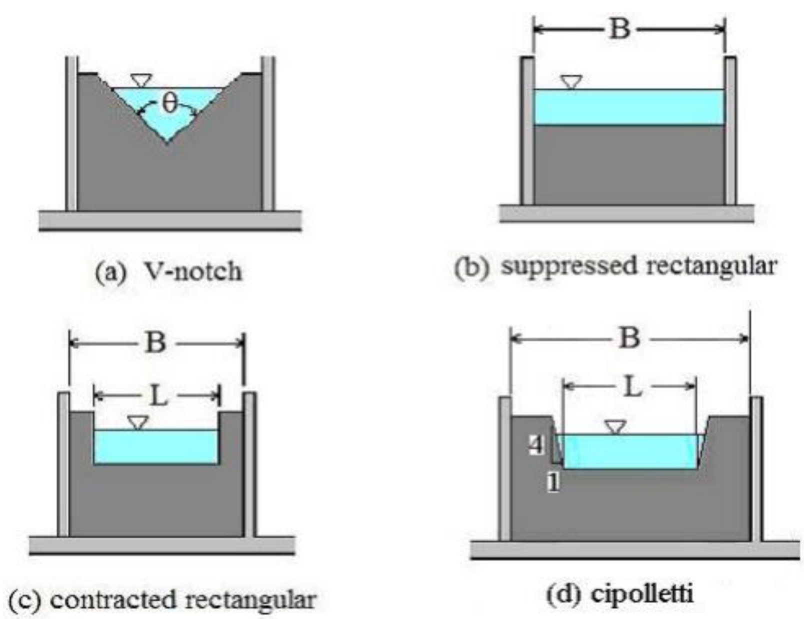
1. AIM AND OBJECTIVE

i. To study various types of Notches used for fluid flow.
ii. To study the basic principles of fluid flow through Weirs and Notches.
iii. To conduct experiment on given V-Notch.
iv. To calibrate the Notch for flow measurement.
v. To calculate the discharge coefficient in open channel.
vi. To tabulate the experimental results and correlated with theoretical experiment.

2. BACKGROUND INFORMATION AND THEORY

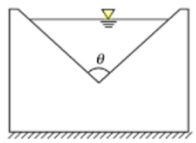
A notch is an opening in the side of a measuring tank or reservoir extending above the free surface. These notches are used to measure discharge of open channel flows, by passing or placing or constructing them across the stream. Notches are generally used for measuring discharge in small open channels or laboratory flumes.

Notches can be of different shapes such as triangular, rectangular, trapezoidal, stepped notch, etc. the bottom of the notch over which the water flows is known as crest or sill and the thin sheet of water flowing through the notch is known as nappe or vein. The edges of the notch are bevelled on the downstream side so as to have a sharp-edged side and crest resulting in minimum contact with the flowing fluid.



The discharge over notch is measured by measuring the head acting over the notch. As water approaches the notch, its surface becomes curved. Therefore, the head over the notch is to be measured at the upstream of the notch where the effect of curvature is minimum. Also, it should be close to the notch so that the loss of energy between head measuring section and notch is negligible. In practical, the head over notch is measured at a distance of 3 to 4 times the maximum head from the notch.

V-notch or Triangular notch



The V-notch or triangular notch is sharp crested notch, which is mainly used to determine the low rate of flow.

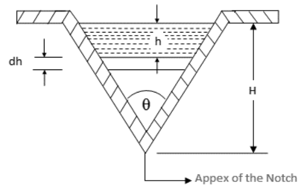


Fig : Triangular Notch

Let,

H = Height of the liquid above the apex of the notch

θ = Angle of the notch

C_d = Coefficient of discharge

From the geometry of the figure, we find that,

$$\text{width of the notch at the water surface} = 2H \tan\frac{\theta}{2}$$

$$\therefore \text{ Area of the strip} = 2(H - h)\tan\frac{\theta}{2}.dh$$

We know that the theoretical velocity of water through the strip $= \sqrt{2gh}$

and discharge over the notch,

$$dq = C_d \times \text{Area of strip} \times \text{Theoretical velocity}$$

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

The total discharge over the whole notch may be found out only by integrating the above equation within the limits 0 and H.

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

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

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

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

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

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

$$\therefore Q = \frac{8}{15} C_d \sqrt{2g} \times \tan\frac{\theta}{2} \times H^{5/2}$$

3. APPARTUS USED

i. Notch
ii. Water tank
iii. Hooke gauge
iv. Bucket
v. Stopwatch
vi. Weighing balance
vii. Piezometer

4. EXPERIMENTAL SET UP

5. EXPERIMENTAL PROCEDURE

i. Note the geometrical aspects of the given Notch.
ii. Note down the initial height of the water in the tank (h_1) using side glass tube when water full up to the crest.
iii. Open the valve and allow water to flow.
iv. Wait for 5 min, until flow becomes steady.
v. Note down the height of the water (h_2) using side glass tube.
vi. Calculate the volumetric flow rate.
vii. Increase the flow rate with the help of the valve and repeat the steps iv to vi.
viii. For different positions of the valve obtain the height and flow rate. Draw a graph of Q vs. h on a lo-log sheet.
ix. By knowing slope it would be possible to calculate C_d.

6. DATA

i. Angle of Notch $\theta_1 = 90^0$, $\theta_2 = 45^0$
ii. Density of water, $\rho_w = 1000$ kg/m^3
iii. Acceleration due to gravity, g = 9.81 m/s^2

7. NOTATIONS

i. h_1-Initial height of liquid in inclined tube at crest level, m
ii. h_2-Initial height of liquid in inclined tube above crest level, m
iii. H – Height of liquid in Notch, m
iv. θ- Angle of Notch
v. t-Time, sec
vi. m- Amount of water collected, kg
vii. V_w – Volume of water collected, m^3
viii. Q_{exp} – Experimental discharge, m^3/s
ix. Q_{the} – Theoretical discharge, m^3/s
x. C_d – Discharge co-efficient
xi. n – intercept on plot of log H vs. log Q
xii. a – slope on plot of log H vs. log Q

8. FORMULAE

i. Head, $H = (h_2 - h_1) \sin \theta$
ii. $V_w = m/ \rho_w$, m^3
iii. $Q_{exp} = V_w/t = m/ \rho_w t$, m^3/s
iv. $Q_{exp} = 8/15 \tan \theta/2 \sqrt{(2 g)} H^{5/2} C_d$, m^3/s

Applying log on both sides

$\log Q_{exp} = \log n + 5/2 \log H$

$y = C + m x$

where, m – slope ~ 2.5

C – Intercept = log n

$C_d = \ln n/\sqrt{(2g)} x\ 8/15$

v. $Q_{the} = Q_{exp}/ C_d$

9. OBSERVATION TABLE

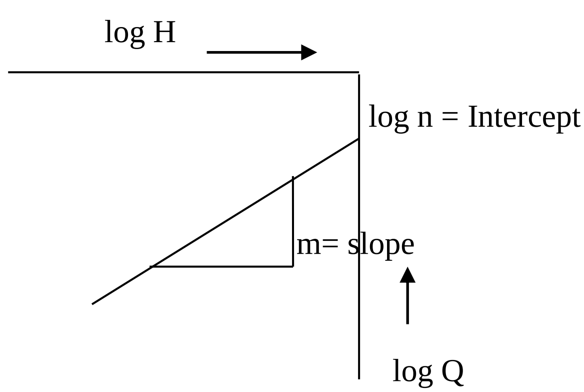
Sl. No.	Inclined scale (h_2) cm	$H = (h_2 - h_1)\sin\theta$ cm	Time (t) s	Amount of water collected m, kg
1.				
2.				
3.				
4.				
5.				
6.				

10. SAMPLE CALCULATIONS

11. CALCULATION TABLE

Sl. No.	H m	V_w m^3	Q_{exp} m^3/s	C_d (from graph)	Q_{the} m^3/s
1.					
2.					
3.					
4.					
5.					
6.					

12. NATURE OF GRAPH



13. RESULTS

14. DISCUSSION ON RESULTS

15. PRACTICAL APPLICATIONS OF EXPERIMENTAL STUDY

16. VIVA QUESTIONS

i. What is Notch? Explain different type of Notch?
ii. What is purpose of Notch?
iii. What is discharge coefficient?

17. REFERENCE

i. McCabe, W.L., *et.al.*, "Unit Operations in Chemical Engineering", 5th edn., McGraw Hill, New York 1993.
ii. Chemical Engineers Handbook**,** Perry & Green, 8th edn, McGraw Hill, 1997.
iii. Badger W.L. and Banchero J.T., "Introduction to Chemical Engineering", Tata McGraw Hill, New York 1997
iv. Coulson J.H. and Richardson J.F., "Chemical Engineering", Vol-I, 5th edn., Asian Books (p) Ltd., New Delhi, 1998.
v. Dr R K Bansal., "A Text Book of Fluid Mechanics" 1st edn., Laxmi Publications (P) Ltd., New Delhi, 2005.