

B. M. S. College of Engineering

Bengaluru -560019

Autonomous Institution Affiliated to Visvesvaraya Technological University (VTU)



Department of Chemical Engineering

Semester -III

Fluid Mechanics Laboratory Manual

19CH3DCFME

Name of the student: -----

USN No.: -----

Batch No.: -----

Signature: -----

Signature of Faculty

LIST OF EXPERIMENTS

CYCLE - I

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Faculty Signature

EXPERIMENT 1 -VENTURIMETER

AIM:

To determine the co-efficient of discharge of the given Venturimeter.

To determine the variation of C_v with N_{re} .

Apparatus:

1. Venturimeter with differential manometer.
2. Measuring tank
3. Stop watch

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.

Components of venturimeter:

a) Cylindrical entrance section: This is the section having the size of a pipe to which it is attached. The venturi meter should be preceded 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 $21 \pm 2^\circ$. 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 $\frac{1}{2}$ to $\frac{3}{4}$ 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

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

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.

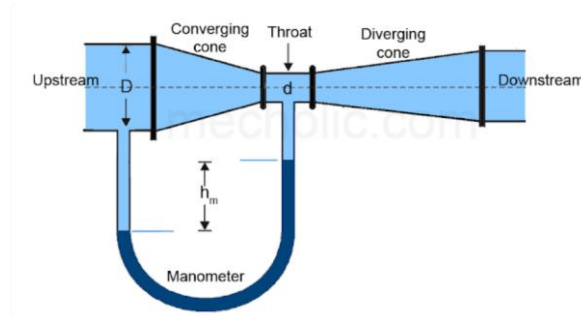


Fig. 1: Schematic of Venturimeter

Let D_1 = Diameter at inlet or at section 1

V_1 = Velocity of fluid at section 1

A_1 = Area at inlet

P_1 = 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

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 \dots (1)$$

Since, the pipe is horizontal So $Z_1 = Z_2$

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} \dots (2)$$

$$\frac{P_1 - P_2}{\rho g} = \frac{V_2^2 - V_1^2}{2g} \dots (3)$$

$$\frac{P_1 - P_2}{\rho g} = h \text{ (Pressure Head in m)}$$

Apply continuity equation at section 1 and section 2

$$A_1 V_1 = A_2 V_2 \dots (4)$$

$$V_1 = \frac{A_2 V_2}{A_1} \dots (5)$$

Substitute eq. (5) in eq. (3)

$$h = (V_2^2 - \left(\frac{A_2 V_2}{A_1}\right)^2) / 2g \dots\dots\dots (6)$$

$$V_2^2 = 2gh \frac{A_1^2}{(A_1^2 - A_2^2)} \dots\dots\dots (7)$$

$$V_2 = \sqrt{2gh \frac{A_1^2}{A_1^2 - A_2^2}} \dots\dots\dots (8)$$

Or

$$V_2 = V_{Throat} = \sqrt{2gh \times \frac{1}{(1 - \beta^4)}}$$

Since Discharge is given by, $Q = A_2 V_2$

$$Q = A_2 \frac{A_1}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{2gh} \dots\dots\dots (9)$$

$$Q_{act} = C_d \times \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{2gh} \dots\dots\dots (10)$$

where C_d is co-efficient of venturimeter and its value is less than 1

Experimental Set Up:

Procedure:

1. Keep the bypass valve fully open and all other valves are fully closed and start the motor.
2. Allow the water to flow through Venturi and regulate with ball valve.
3. Remove any entrapped air bubbles from the manometer. After steady state is reached, note down the difference in level of manometric fluid.
4. Note down the time taken for water in collecting tank to rise for a given level.
5. Repeat the experiment for 6 readings for different opening of the ball valve and closing the bypass gate valve.

Observation Table:

Sl.No.	Manometer Reading		Difference $R_m = \dots m$	Discharge or Actual Flow Rate (Q_{act})	
	LHS(mm)	RHS(mm)		Height, m	Time, sec.
1.					
2.					
3.					
4.					
5.					
6.					

Specification:

Pipe Diameter, D_p	= 25.4 mm
Throat Diameter, D_{throat}	= 12.5 mm
Density of Manometer Fluid, ρ_m	= 13600 kg/m ³
Density of fluid flowing through pipe, ρ_f	= 1000 kg/m ³
Area of overhead water tank, A_{tank}	= 0.125 m ²

Calculation:

1. Manometer Reading

$$R_m = LHS - RHS, m$$

2. Fluid Head Lost

$$h = \frac{\rho_m - \rho_f}{\rho_f} \times R_m, m \text{ of water}$$

3. Throat Velocity

$$V_{Throat} = \sqrt{2gh \times \frac{1}{(1 - \beta^4)}}$$

$$\text{where, } \beta = \frac{D_{Throat}}{D_{Pipe}}$$

4. Actual Flow Rate

$$Q_{act} = \frac{(A_{Tank} \times h_{Tank})}{time}, m^3/s$$

5. Theoretical Flow Rate

$$Q_t = V_{throat} \times \text{cross sectional area of Throat}, m^3/s$$

6. Coefficient of discharge

$$C_v = \frac{Q_{act}}{Q_t}$$

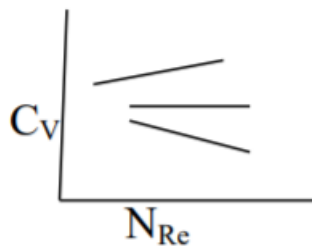
7. Actual Velocity

$$V_{act} = \frac{Q_{act}}{A_p}, m/s$$

8. Reynold's Number

$$N_{Re} = (D_p \times V_{act} \times \rho_f) / \mu$$

9. Plot variation of C_v with N_{Re} (use semi-log graph)



Result Table:

Sl.No.	Difference Rm =....m	h, m of water	V_{Throat} , m/s	Q_t , m^3/s	Q_{act} , m^3/s	C_v	V_{act} , m/s	N_{Re}
1.								
2.								
3.								
4								
5.								
6.								

Discussion and Inference:

Experiment No.2 - ORIFICEMETER

Aim:

To determine the co-efficient of discharge of the given Orificemeter.

To determine the variation of C_o with N_{re} .

Apparatus:

1. Orificemeter with differential manometer.
2. Measuring tank
3. Stop watch

Theory:

Orifice meter is basically defined as a device which is used for measuring the rate of flow of fluid flowing through a pipe. Orifice meter is also known as Orifice plate. Orifice meter works on the principle of Bernoulli's equation and continuity equation.

Orifice meter is less costly as compared to the Venturimeter. Venturimeter is also very reliable flow measuring device. There are some pressure losses in Venturimeter and it is usually used in larger volume liquid and gas flows. Venturimeter is expensive due to complexity of its design. Therefore, in order to determine the rate of flow of fluid through small pipe lines, orifice meter is better to use as compared to Venturimeter.

Orifice meter consists of one flat circular plate and this circular plate will have one circular sharp edge hole bored in it. The circular sharp edge hole is termed as orifice. Diameter of orifice will be 0.5 times of diameter of pipe through which fluid is flowing, though it may vary from 0.4 to 0.8 times of diameter of pipe.

Orifice plate is installed in pipe between two flanges of pipe. Orifice will restrict the flow of fluid and will reduce the cross-sectional area of flow passage. A differential pressure will be developed across the orifice plate. Due to creation of pressure difference, we will be able to determine the rate of fluid flow through the pipe.

Types of Orifice meter

Orifices are usually of concentric types i.e. orifice will be concentric with the pipe line. But, there are few more designs available as mentioned here

1. Eccentric orifice plate
2. Sharp edge orifice plate
3. Segmental orifice plate
4. Conical orifice plate

Consider two sections i.e. section 1 and section 2 as displayed here in following figure. A differential manometer will be connected as displayed in figure at section 1, which will be approximate 1.5 to 2 times the diameter of pipe upstream from the orifice, and at section 2, which will be approximate 0.5 times the diameter of the orifice on the downstream side from the orifice plate

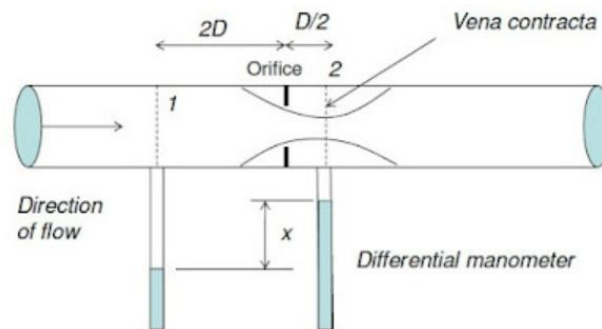


Fig. 1: Schematic of Orifice meter

Let D_1 = Diameter at inlet or at section 1

V_1 = Velocity of fluid at section 1

A_1 = Area at inlet

P_1 = 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

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

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 \dots (1)$$

Since, the pipe is horizontal So $Z_1 = Z_2$

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} \dots (2)$$

$$\frac{P_1 - P_2}{\rho g} = \frac{V_2^2 - V_1^2}{2g} \dots (3)$$

$$\frac{P_1 - P_2}{\rho g} = h \text{ (Pressure Head in m)}$$

$$V_2 = \sqrt{2gh + V_1^2} \dots (4)$$

Let A_0 is the area of the orifice

Co-efficient of contraction, $C_C = A_2/A_0$

From continuity equation:

Apply continuity equation at section 1 and section 2

$$A_1 V_1 = A_2 V_2 \dots (5)$$

$$V_1 = \frac{A_0 C_c}{A_1} \times V_2 \dots\dots\dots (6)$$

$$V_2 = \sqrt{2gh + \frac{A_0^2 C_c^2 V_2^2}{A_1^2}} \dots\dots\dots (7)$$

$$V_2 = \frac{\sqrt{2gh}}{\sqrt{1 - \frac{A_0^2 C_c^2}{A_1^2}}} \dots\dots\dots (8)$$

Since Discharge is given by, $Q = A_2 V_2$

$$Q = A_2 V_2 = V_2 A_0 C_c A_2 = \frac{A_0 C_c}{\sqrt{1 - \frac{A_0^2}{A_1^2} \times C_c^2}} \times \sqrt{2gh} \dots\dots\dots (9)$$

If C_d is the co-efficient of discharge for orifice meter, which is defined as

$$C_d = C_c \frac{\sqrt{1 - \frac{A_0^2}{A_1^2}}}{\sqrt{1 - C_c^2 \times \frac{A_0^2}{A_1^2}}} \dots\dots\dots (10)$$

$$Q = C_d \times \frac{A_0 A_1 \sqrt{2gh}}{\sqrt{A_1^2 - A_0^2}} \dots\dots\dots (11)$$

Experimental Set Up:

Procedure:

1. Keep the bypass valve fully open and all other valves are fully closed and start the motor.
2. Allow the water to flow through Orifice and regulate with ball valve.
3. Remove any entrapped air bubbles from the manometer. After steady state is reached, note down the difference in level of manometric fluid.
4. Note down the time taken for water in collecting tank to rise for a given level.
5. Repeat the experiment for 6 readings for different opening of the ball valve and closing the bypass gate valve.

Observation Table:

Sl.No.	Manometer Reading		Difference $R_m = \dots m$	Discharge or Actual Flow Rate (Q_{act})	
	LHS(mm)	RHS(mm)		Height,m	Time, sec.
1.					
2.					
3.					
4					
5.					
6.					

Specification:

Pipe Diameter, D_p	= 25 mm
Throat Diameter, D_{Throat}	=12.5 mm
Density of Manometer Fluid, ρ_m	=13600 kg/m ³
Density of fluid flowing through pipe, ρ_f	=1000 kg/m ³
Area of overhead water tank, A_{tank}	=0.125 m ²

Calculation:

1. Manometer Reading

$$R_m = LHS - RHS, m$$

2. Fluid Head Lost

$$h = \frac{\rho_m - \rho_f}{\rho_f} \times R_m, m \text{ of water}$$

3. Throat Velocity

$$V_{orifice} = \sqrt{2gh \times \frac{1}{(1 - \beta^4)}}$$

$$\text{where, } \beta = \frac{D_{orifice}}{D_{Pipe}}$$

4. Actual Flow Rate

$$Q_{act} = \frac{(A_{Tank} \times h_{Tank})}{time}, m^3/s$$

5. Theoretical Flow Rate

$$Q_t = V_{orifice} \times \text{cross sectional area of Orifice}, m^3/s$$

6. Coefficient of discharge

$$C_o = \frac{Q_{act}}{Q_t}$$

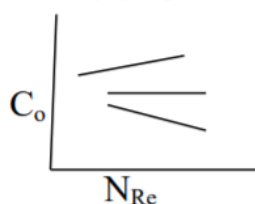
7. Actual Velocity

$$V_{act} = \frac{Q_{act}}{A_p}, m/s$$

8. Reynold's Number

$$N_{Re} = (D_p \times V_{act} \times \rho_f) / \mu$$

9. Plot variation of C_o with N_{Re} (use semi-log graph)



Result Table:

Sl.No.	Difference Rm =....m	h, m of water	$V_{orifice},$ m/s	$Q_t,$ m^3/s	$Q_{act},$ m^3/s	C_o	$V_{act},$ m/s	N_{Re}
1.								
2.								
3.								
4								
5.								
6.								

Discussion and Inference:

Experiment No. 3 – FLOW THROUGH CIRCULAR PIPES

Aim:

To plot the friction factor charge (Moody's chart) for flow through circular pipes.

Apparatus:

Circular conduits setup (1", 3/4", 1/2"), stop watch.

Theory:

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 centre 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.

The significant properties of the pipe are their internal diameter, length and roughness ratio ϵ/D where, D is the inside diameter of the pipe and ϵ is average height of the projections of reference inside the pipe), viscosity and density of the fluid.

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.

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 $N_{Re} < 2100$
- turbulenttransient when $2100 < N_{Re} < 4000$
- transient turbulent 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.

Frictional Pressure Drop

$$(-\Delta P)_f = \rho g h_{fs} \dots \dots \dots (1)$$

Where,

$(-\Delta P)_f$ = frictional pressure drop

h_{fs} = frictional head loss due to skin friction

ρ = fluid density

g = acceleration due to gravity

$$h_{fs} = \frac{(-\Delta P)_f}{\rho g} = \frac{4\tau_w L}{\rho g D} \dots \dots \dots (2)$$

Where τ_w is the shear stress at the wall of the pipe, L is the length of the pipe. τ_w is 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 ($V^2/2g$) and density ρ

$$f = \frac{\tau_w}{\rho V^2/2} \dots \dots \dots (3)$$

$$\frac{\text{wall shear stress}}{\text{density} \times \text{velocity head}} \times h_{fs} = \frac{(-\Delta P)_f}{\rho g} = 4f \left(\frac{L}{D} \right) \left(\frac{V^2}{2g} \right) \dots \dots \dots (4)$$

Where f is the Fannings 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

The friction factor can be determined by other two equations:

$$\text{For } N_{Re} < 2100, \text{Laminar flow } f = \frac{16}{N_{Re}}$$

$$\text{For } N_{Re} > 4000, \text{turbulent flow } f = \frac{0.046}{(N_{Re})^{0.2}}$$

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.

Experimental Set-Up:

Procedure:

1. Keep the bypass valves fully open and the other valves closed and start the pump.
2. Select the pipe for which the pressure drop is to be determined and connect the manometer across the pipe.
3. Adjust the flow rate at any required value.
4. Measure the flow rate by collecting the water in the tank for a known period of time.
5. Repeat the experiment for different flow rates and different pipes.
6. Calculate f , N_{Re} and report.
7. Plot f vs N_{Re} on log-log graph.

Specification:

Length of pipe	= 1.5 m
Diameter of pipe, D_1 "	1" = 2.54 cm
Diameter of pipe, $D_{3/4}$ "	$\frac{3}{4}$ " = 1.905 cm
Diameter of pipe, $D_{1/2}$ "	$\frac{1}{2}$ " = 1.27 cm
Area of water collecting tank, A_{tank}	=0.125 m ²

Observation Table:**Pipe Diameter:**

Sl.No.	Manometer Reading		Difference $R_m = \dots m$	Discharge or Actual Flow Rate (Q_{act})	
	LHS(mm)	RHS(mm)		Height,m	Time, sec.
1.					
2.					
3.					
4					
5.					
6.					

Pipe Diameter =.....

Sl.No.	Manometer Reading		Difference $R_m = \dots m$	Discharge or Actual Flow Rate (Q_{act})	
	LHS(mm)	RHS(mm)		Height,m	Time, sec.
1.					
2.					
3.					
4					
5.					

Calculation:

1. Manometer Reading

$$R_m = LHS - RHS, m$$

2. Pressure Drop

$$\Delta P = R_m(\rho_m - \rho_f)g \text{ N/m}^2$$

3. Volumetric Flow Rate

$$Q_{act} = \frac{(A_{Tank} \times h_{Tank})}{time}, m^3/s$$

4. Average Velocity

$$V = \frac{Q}{A_{pipe}}, A_{pipe} \text{ is cross sectional area of pipe}$$

5. Reynolds Number

$$N_{Re} = (D_p \times V_{act} \times \rho_f) / \mu$$

6. Friction Factor

$$f = \frac{\Delta P \times D_{pipe}}{2\rho_f V^2 L}$$

Result Table:

Pipe Diameter =.....

Sl.No.	Difference Rm =....m	ΔP	$Q_{act},$ m^3/s	$V, m/s$	f	N_{Re}
1.						
2.						
3.						
4						
5.						
6.						

Pipe Diameter =

Sl.No.	Difference Rm =....m	ΔP	$Q_{act},$ m^3/s	$V, m/s$	f	N_{Re}
1.						
2.						
3.						
4						
5.						
6.						

Discussion and Inference:

EXPERIMENT 4 – FLOW THROUGH NON-CIRCULAR PIPES

Aim:

To study the flow characteristics of a fluid through a non-circular pipe and establish the relationship between friction factor and Reynolds number for various flow conditions.

Apparatus:

Experimental setup with square and rectangular pipe, Manometer, Bucket and stop watch for measuring volumetric flow rate.

Theory:

A non-circular pipe is simply a square or a rectangular pipe. The friction in the long straight channels of non-circular cross section can be estimated by using the equation for circular pipes if the diameter in the Reynold number and the definition of friction factor is taken as the equivalent diameter as explained later. Square and rectangular sections are encountered often in industries and study of the behaviour of the fluid flow through such channels is of use.

Experimental Set-Up:

Procedure:

1. Keep the bypass valves fully open and the other valves closed and start the pump.
2. Select the pipe for which the pressure drop is to be determined and connect the manometer across the pipe.
3. Adjust the flow rate at any required value.
4. Measure the flow rate by collecting the water in the tank for a known period of time.
5. Repeat the experiment for different flow rates and different pipes.
6. Calculate f , N_{Re} and report.
7. Plot f vs N_{Re} on log-log graph.

Specification:

Length of rectangular/square pipe	= 1.5 m
Width or Breadth of square pipe, D_1 "	1" = 2.54 cm
Width or Breadth of rectangular pipe, D_1 "	$\frac{3}{4}$" = 1.905 cm
Area of water collecting tank, A_{tank}	=0.125 m²

Observation Table:

Pipe =.....

Sl.No.	Manometer Reading		Difference Rm =....m	Discharge or Actual Flow Rate (Q_{act})	
	LHS(mm)	RHS(mm)		Height,m	Time, sec.
1.					
2.					
3.					
4					
5.					
6.					

Pipe =.....

Sl.No.	Manometer Reading		Difference Rm =....m	Discharge or Actual Flow Rate (Q_{act})	
	LHS(mm)	RHS(mm)		Height,m	Time, sec.
1.					
2.					
3.					
4					
5.					
6.					

Calculation:

1. Manometer Reading

$$R_m = LHS - RHS, m$$

2. Equivalent diameter of square pipe

$$D_E = w \text{ or } b$$

3. Equivalent diameter of square pipe

$$D_E = 2(w \times b)/(w + b)$$

Where, w = width of pipe and b = breadth of pipe

4. Pressure Drop

$$\Delta P = R_m(\rho_m - \rho_f)g \text{ N/m}^2$$

5. Volumetric Flow Rate

$$Q_{act} = \frac{(A_{Tank} \times h_{Tank})}{time}, m^3/s$$

6. Average Velocity

$$V = \frac{Q}{A_{pipe}}, A_{pipe} \text{ is equivalent cross sectional area of pipe}$$

7. Reynolds Number

$$N_{Re} = (D_E \times V_{act} \times \rho_f) / \mu$$

8. Friction Factor

$$f = \frac{\Delta P \times D_E}{2 \rho_f V^2 L}$$

Result Table:

Pipe =

Sl.No.	Difference Rm =....m	ΔP	$Q_{act},$ m^3/s	$V, m/s$	f	N_{Re}
1.						
2.						
3.						
4						
5.						
6.						

Pipe =

Sl.No.	Difference Rm =....m	ΔP	$Q_{act},$ m^3/s	$V, m/s$	f	N_{Re}
1.						
2.						
3.						
4						
5.						
6.						

Discussion and Inference:

Experiment No. 5- CENTRIFUGAL PUMP

Aim:

To conduct the performance test on centrifugal pump under varying condition of delivery head and speed

To plot the operating characteristic curves.

Apparatus:

The centrifugal test rig experiment is a self-contained unit operated on closed circuit basis. The pump, electric motor, collecting tank, sump tank, control panel, Pressure gauge, Vacuum gauge etc.

Theory:

Centrifugal pump is a roto-dynamic machine that imparts energy to fluid by rotating impeller to increase the pressure of a fluid. These pumps are commonly used to move liquids through a piping system. When the fluid enters the pump impeller along or near to the rotating axis it is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits into the downstream piping system. Centrifugal pumps are used for large discharge through smaller heads. Centrifugal pumps generate high rotational velocities and then convert the resulting kinetic energy of the liquid to pressure energy.

The fluid enters the inlet of the centrifugal pump under atmospheric pressure, and flows into the eye of the impeller. The Centrifugal force exerted on the liquid by the rotating impeller, moves the liquid away from the impeller eye and out along the impeller vanes to their extreme tip where the liquid is then forced against the inside walls of the volute and out through the discharge of the pump.

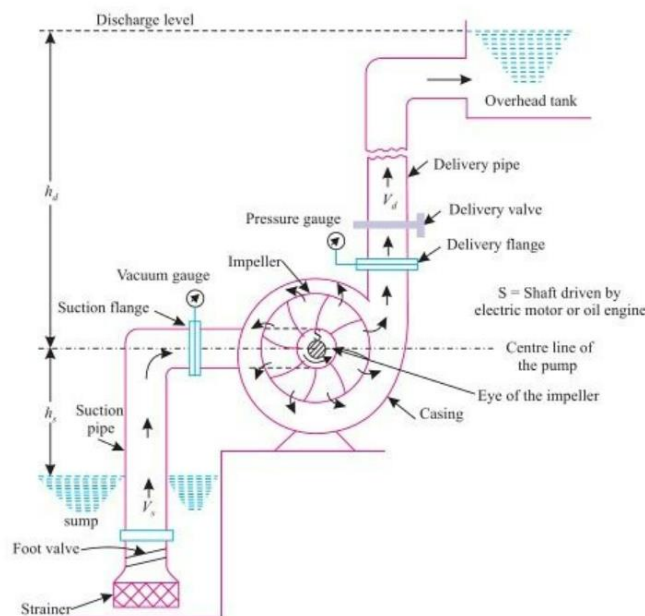


Fig.1 : Schematic of Centrifugal Pump

Experimental Set-Up:

Procedure:

1. Connect the power cable.
2. Keep the delivery and suction valve open fully.
3. Fill the sump with clean water. 4) Air vent the pump by using air vent valve.
4. Select the speed by adjusting the pulley.
5. Switch on the mains and the pump, water starts flowing to the measuring tank.
6. Note down the pressure gauge, vacuum gauge and time for number of revolutions of energy meter disc at full opening of delivery and suction valve.
7. Operate the butterfly valve to note down the collecting tank reading against the known height and time taken in seconds.
8. Repeat the experiments for different closings of the valves either at suction or delivery valve and note down the above readings.

Specification:

Energy meter constant (EMC)	= 750 rev/k Wh
Area of water collecting tank, A_{tank}	= 0.125 m ²

Observation Table:

Sl. No.	Speed of the Pump, rpm	Suction Head HS (mm Hg)	Delivery Head (HD) kg/cm ²	Time for 5 Revolutions of Energy Meter, sec	Volumetric Flow Rate Q, m ³ /s	
					Height, cm	Time, sec.
1.						
2.						
3.						
4.						
5.						
6.						

Calculation:

$$H_D = \text{Delivery Head, in } \frac{Kg}{cm^2}$$

$$H_S = \text{Suction Head, in mm Hg.}$$

1. Total head

$$H_T = H_D + H_S = m \text{ of water}$$

$$H_D = 760 \text{ mm Hg} = 10.2 \text{ m of water}$$

$$H_S = 1 \frac{kg}{cm^2} = 10 \text{ m of water}$$

2. Volumetric Flow Rate

$$Q = \frac{(A_{Tank} \times h_{Tank})}{time}, m^3/s$$

$$\text{Energy Meter Constant (EMC)} = 750 \frac{rev}{kWh}$$

3. k = No of Energy meter revolutions in time, t sec.

4. Input Power (Theoretical)

$$= \frac{k \times 60 \times 60 \times 1000}{EMC \times 746 \times t}, HP$$

5. I_{HP} (Actual)

$$= I_{HP} (Theoretical) \times 0.6, HP$$

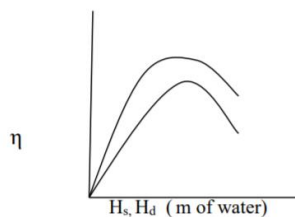
6. Output Power = O_{HP}

$$= \frac{1000 \times Q \times H_T}{75}, HP$$

7. Efficiency of pump

$$\eta (\%) = \frac{O_{HP}}{I_{HP}} * 100$$

8. Plot the graph for different suction and delivery head verses pump efficiency.

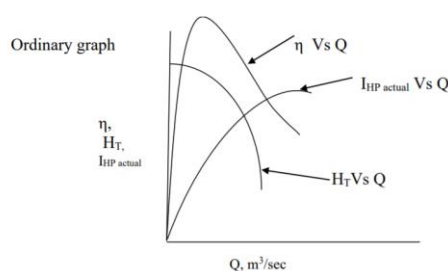


9. Plot characteristic operating curves

The pump characteristic curves can be defined as ‘the graphical representation of a particular pump’s behaviour and performance under different operating conditions.

During operation of a pump, the pump must run constantly with the speed of the prime mover; this constant speed is usually the design speed. The set of main characteristics curves which corresponds to the design speed is mostly used in pump operation, and hence such curves are known as the operating characteristics curves.

1. Head versus Discharge Curve
2. Efficiency versus Discharge Curve
3. Power versus Discharge Curve



Result Table:

Sl. No.	$H_T = m \text{ of water}$	$Q, m^3/s$	I_{HP}, Actual	O_{HP}	$\eta (\%)$
1.					
2.					
3.					
4.					
5.					
6.					

Discussion and Inference:

Experiment No. 6- FLOW THROUGH PACKED BED

AIM:

- 1) To verify the relationship between the velocity of the fluid and pressure drop per unit length of packing.
- 2) To verify Ergun's equation.

Apparatus:

Packed bed unit, stop watch etc.

Theory:

Packed beds are the 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 rate. 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: Rate of fluid flow, Viscosity and density of the fluid, Closeness and orientation of packing, Size shape and surface of the particles.

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. 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.

The Ergun equation:

Assumptions

1. The particles are packed in random.
2. There is no channelling in the packed bed.
3. The diameter of the packing is much smaller than the diameter of the column as well.
4. The maximum recommended particle diameter is one-fifth of the column diameter.
5. The velocity, particle diameter and void fraction behaves as a bulk behavior and hence used an average value.

As the fluid passes through the bed, it does so through empty spaces (Voids) in the bed. The voids form continuous channels through the bed. These channels need not be of same length and diameter. While the flow may be laminar through some channels, it may be turbulent in other channels. The resistance due to friction per unit length of the bed can be the sum of two terms:

1. Viscous drag force which is proportional to the first power of fluid velocity, V .
2. Inertial force which is proportional to the square of the fluid velocity, V .

Since V , velocity in the channel is difficult to estimate, V is substituted by V_o , the velocity through the empty cross section of the column. V_o is related to V by the expression $V_o = \epsilon V$ where ϵ is the bed voidage or porosity. The total surface area of the particles in the bed which come in contact with the fluid is a function of specific surface of the particle and its sphericity and the voids in the bed. Taking all these facts into considerations ERGUN'S EQUATION has been derived to estimate the pressure drop for flow of fluid through a packed bed.

$$\left(\frac{\Delta P}{L\rho}\right) \left[\frac{\epsilon^3}{(1-\epsilon)^2}\right] \left(\frac{D_p}{V_o^2}\right) = 150 \left[\frac{(1-\epsilon)\mu}{D_p V_o \rho}\right] + 1.75 = f_p$$

$$\text{Where } f_p = 150 \frac{(1-\epsilon)}{(NRe)_p} + 1.75$$

$$(NRe)_p = \frac{\mu}{D_p V_o \rho}$$

At very low values of $(NRe)_p$, the term $150 \left[\frac{(1-\epsilon)\mu}{D_p V_o \rho}\right]$ is very large compared to 1.75. In other words, viscous drag force predominates. As $(NRe)_p$ increases, f_p approaches 1.75. For any range of $(NRe)_p$, the total friction loss is an additive of resistance due to viscous forces and resistance due to inertial forces.

Experimental Set Up:

Procedure:

1. Note the dimensions of the packing material and diameter and height of the packed bed.
2. Check for and remove any entrapped air bubbles from the manometer.
3. Keep the bypass valve fully open and inlet valve fully closed. Start the pump and regulate the flow of water through the bypass valve.
4. Open the supply valve slowly and adjust for the required flow rate through the packed bed using the rotameter. When steady state is reached, record the manometer reading.
5. Repeat the experiment by slowly varying the flow rate starting from the minimum flow rate and going to a maximum value.
6. Calculate f_{PT} , f_{PE} and $(NRe)_P$ and report.

Observation Table:

S. No.	Manometer Reading		Rm = (LHS–RHS) x 10 ⁻² m	Flow Rate, (LPM)
	LHS, cm	RHS, cm		
1.				
2.				
3.				
4.				
5.				
6.				

Specifications:

Diameter of the Packed column ($D_{Col.}$)	= 0.073 m
Length of the Packed column (L)	= 1 m
Packing diameter D_p	=12.5 mm or 12.5×10^{-3} m
Shape factor, ϕ_s for rashig ring	= 1

FORMULAE:

1. Manometer reading $R_m = LHS - RHS, m$

2. Fluid head lost, $H = (\rho_m - \rho_f / \rho_f) R_m, m \text{ of water}$

3. Cross sectional area of column, $A = \frac{\pi}{4} \times (D_c)^2, m^2$

4. Superficial Velocity of fluid through packed bed, $V_o = Q/A, m/sec$

Where Q = Rotameter reading in LPM to be converted to m^3/sec

5. Pressure drop per unit length of packing

$$\frac{\Delta P}{L} = \frac{[R_m g (\rho_m - \rho_f)]}{l}$$

6. Modified Reynold's Number

$$(NRe)_p = \frac{D_{particle} V_o \rho_f}{\mu}$$

7. For Spherical particle (Rasching ring)

$$D_p = \frac{6V_p}{(S_p \phi_s)}$$

Where ϕ_s is sphericity and is defined as the surface – volume ratio of the sphere having the same volume as Rasching ring to the surface volume ration of the sphere of the particle. (Surface area of the sphere having the same volume as the particle to the surface area of the particle)

8. Friction factor for packed bed. (Theoretical)

$$f_{PT} = \left(\frac{\Delta P}{L} \rho_f \right) \left\{ \frac{\epsilon^3}{(1 - \epsilon)^2} \right\} \left(\frac{D_p}{V_o^2} \right) \phi_s$$

9. Friction factor for packed bed. (Experimental)

$$f_{PE} = \frac{150(1 - \epsilon)}{(NRe)_p} + 1.75$$

Where ϵ porosity = Volume of voids / Volume of bed

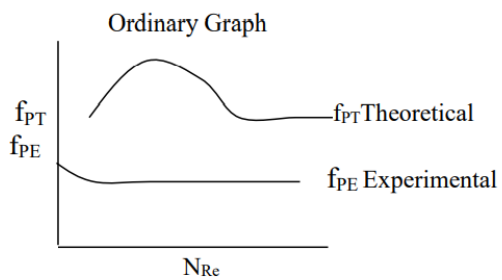
Volume of voids = approximately 2.5 liters or $2.5 \times 10^{-3} m^3$

Volume of bed = Cross sectional Area of column (A) $\times$ Length of Bed

Result Table:

S.No.	R_m, m	$\Delta P/L, m$	$Q_{act} m^3/s$	$V_o m/s$	N_{Re}	f_{PE}	f_{PT}
1.							
2.							
3.							
4.							
5.							
6.							

Plot Graph:



Discussion and Inference:

Experiment No. 7- FLOW THROUGH HELICAL COILS

Aim:

1. To determine the critical Reynolds number of a fluid flowing through a helical coil.
2. To compare the pressure drop in a Helical coil with that in a straight pipe of same length, inside diameter and surface roughness.
3. To determine the friction factor for flow of a liquid through a Helical coil.

Apparatus:

Helical coil setup, stop watch.

Theory:

Flow through helical coil is used for heating or cooling in process tanks. When a fluid flow through a curved tube, centrifugal force acting upon the various elements of fluid moving with different velocities causes secondary circulation. Secondary flow results in higher heat transfer characteristics. Further secondary flow stabilizes the laminar flow leading of a higher critical Reynolds number for transition from laminar to turbulent flow. 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.

The critical Reynolds number is associated with the laminar-turbulent transition, in which a laminar flow becomes turbulent. The critical Reynolds number is different for every geometry.

Experimental Set Up:

Procedure:

1. Keep the bypass valve fully open and start the pump.
2. Allow water to flow through inner helical coil and regulate the with the gate valve.
3. Remove any entrapped air bubbles from the manometer.
4. After the steady state is reached, note down the difference level of manometric fluid.
5. Note the time required for the liquid level in the collection tank to increase by 5 cm.
6. Repeat the experiment for at least eight flowrates starting from minimum flow rate to maximum value.
7. Calculate N_{Re} , $N_{Re,c}$, H_c , H_s , f_c , f_s

Specification:

Diameter of pipe, D_{pipe}	= 0.015 m
Length of straight pipe, L	= 5.665 m
Diameter of coil, D_c	= 0.45 m
Viscosity of fluid flowing, μ_f	= 1×10^{-3} N-S/m ²

Observation Table:

S. No.	Manometer Reading		Rm = (LHS–RHS)×10 ⁻² m	Actual Flow rate /Discharge (Q_{act})	
	LHS, cm	RHS, cm		Height, m	Time, sec.
1.					
2.					
3.					
4.					
5.					
6.					

FORMULAE :

1. Manometer reading $R_m = LHS - RHS, m$
2. Head loss in coil, $H_C = R_m \{(\rho_m - \rho_f)/\rho_f\}, m \text{ of } H_2O$
3. Head loss in straight tube of same length as coil for same flow rate,

$$H_s = 4f \left(\frac{L}{D}\right) \left(\frac{V^2}{2g}\right), m \text{ of } H_2O$$

$$\text{where } f = \frac{16}{N_{Re}} \text{ for Laminar flow } (N_{Re} < 2100)$$

$$\text{and } f = 0.046(N_{Re})^{-0.2} \text{ for turbulent flow } (N_{Re} > 4000)$$

$$4. \text{Volumetric flow rate } Q = \frac{c/s \text{ Area of Tank } (A) \times \text{Height of Tank}}{\text{Time}}$$

$$5. \text{Average velocity } V = Q/A_{pipe}$$

$$\text{Where } A \text{ is the cross area of the pipe } A_{pipe} = \frac{\pi * (D_{pipe})^2}{4}$$

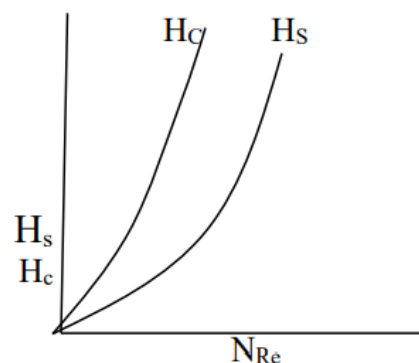
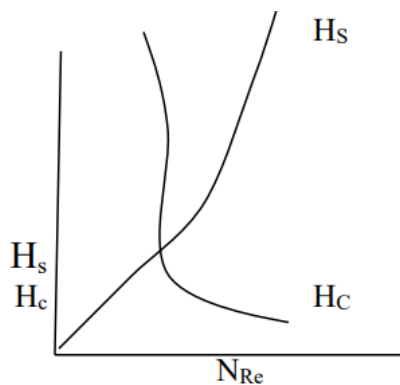
$$N_{Re} = \frac{D_{pipe} V \rho_f}{\mu_f},$$

where D_{pipe} = Diameter of Pipe & D_c = Diameter of coil

$$6. \text{Critical Reynolds number } N_{Re,c} = 2100(1 + 12\sqrt{D_p/D_c})$$

$$7. \text{Friction factor in coil } f_c = 0.08 (N_{Re})^{-0.25} + 0.01(D_p/D_c)^{0.5}$$

Plot Graph (Ordinary Graph)



Result Table:

S.No.	R_m, m	V, m	$Q_{act} m^3/s$	N_{Re}	H_s, m of H_2O	$N_{Re,c}$	f_c	H_c, m of H_2O
1.								
2.								
3.								
4.								
5.								
6.								

Discussion and Inference:

Experiment No. 8- FLOW THROUGH PIPE FITTINGS

Aim:

To determine the pressure drop characteristics for the flow of a fluid through different types of Fittings and plot the characteristics curves.

Apparatus:

Experimental setup with pipe connections and different fittings, manometer, stop watch and collection tank for measuring flow rates.

Theory:

Two types of energy loss predominate in fluid flow through a pipe network; major losses, and minor losses. Major losses are associated with frictional energy loss that is caused by the viscous effects of the medium and roughness of the pipe wall. Minor losses, on the other hand, are due to pipe fittings, changes in the flow direction, and changes in the flow area.

Calculating pressure losses is necessary for determining the appropriate size pump. Knowledge of the magnitude of frictional losses is of great importance because it determines the power requirements of the pump forcing the fluid through the pipe. For example, in refining and petrochemical industries, these losses have to be calculated accurately to determine where booster pumps have to be placed when pumping crude oil or other fluids in pipes to distances thousands of kilometres away.

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 lines with many fittings, the friction loss from the fittings may be greater than that from the straight pipe.

Pressure losses in fittings is usually represented by equivalent length (L_e). It is the length of a straight pipe that offers same resistance to flow as that offered by the fitting. The ratio L_e/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 pipeline, 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.

Experimental Set UP:

Procedure:

- 1) A particular fitting is chosen (say Globe Valve) and the manometer is fitted across this fitting.
- 2) The inlet valve and manometer connections are properly ensured.
- 3) Keep the bypass valve fully open and start the pump.
- 4) The inlet valve is regulated to allow water to flow through the pipe and fitting.
- 5) After steady state conditions are attained, the manometer reading and the volumetric flow rate are noted.
- 6) The experiment is repeated for various flow rates till eight readings are obtained.
- 7) The manometer connection is changed for other Fittings and experiment is to be repeated
- 8) Calculate $Q, V, N_{Re}, f, L_e/D_p$ and report.

Observation Table:**Type of Fitting.....**

S. No.	Manometer Reading			Actual Flow rate /Discharge (Q_{act})		
	LHS, cm	RHS, cm	R_m , m	Height, m	Time, sec.	Q_{act} ,
1.						
2.						
3.						
4.						
5.						
6.						

Type of fitting.....

S. No.	Manometer Reading			Actual Flow rate /Discharge (Q_{act})		
	LHS, cm	RHS, cm	R_m , m	Height, m	Time, sec.	Q_{act} ,
1.						
2.						
3.						
4.						
5.						
6.						

Specification:

Inner diameter of pipe with fitting, D_p	= 21 mm
Length of pipe between two fittings pipe, L	= 22 cm

Calculation:

1. Volumetric flow rate, $Q = \frac{c/s \text{ area of tank} \times \text{Height}}{\text{Time}}, \text{m}^3/\text{sec}$

2. Velocity = Q/A_p , m/sec where A_p = Cross Sectional area of the pipe

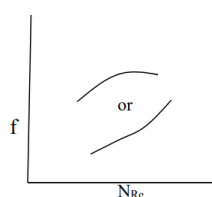
3. Manometer reading $R_m = (\text{LHS} - \text{RHS}), \text{m}$

4. Fluid head loss, $H = R_m \frac{\rho_m - \rho_f}{\rho_f}$, m of water

5. Reynolds Number, $N_{Re} = \frac{D_p V \rho_f}{\mu_f}$, Dimensionless

For Laminar flow, friction factor, $f = 16/N_{Re}$, $Le/D_p = g H / 2fV^2$, where Le = Equivalent length of fitting and D_p = Diameter of pipe.

For Turbulent flow ($N_{Re} > 2100$), friction factor = $0.079 / [(N_{Re})^{0.25}]$



7. Plot Graph: f vs N_{Re} (Log – Log)

Result Table:

Type of fitting.....

S.No.	R_m, m	$\Delta H, m$	$Q_{act}, m^3/s$	N_{Re}	$V, m/s$	$N_{Re,c}$	f	L_e/D_p
1.								
2.								
3.								
4.								
5.								
6.								

Type of fitting.....

S.No.	R_m, m	$\Delta H, m$	$Q_{act}, m^3/s$	N_{Re}	$V, m/s$	$N_{Re,c}$	f	L_e/D_p
1.								
2.								
3.								
4.								
5.								
6.								

Discussion and Inference

Experiment No. 9- CALIBRATION OF ROTAMETER

Aim:

To calibrate the rotameter and to study the variation between indicated and actual flow rate.

APPARATUS

Rotameter, Pump, Water tank (Source), Discharge tank fitted with level indicator.

Theory:

A rotameter is a variable area meter which measures the flow rate of liquid in a closed tube. It consists essentially of a gradually tapered glass tube, containing a float, mounted vertically in a frame, with the large end up. The tapered tube has a graduated scale to indicate volumetric flow rate. The fluid flows upward through the tapered tube and suspends the float. An indicator floats at a steady value when the forces on it are equal. The main forces are the weight of the float (downward) and the drag force of the fluid (upward). Other forces are the difference in pressure over the float and the buoyancy force of the displaced fluid, which increases with pressure. The static equilibrium of the float is defined by the weight of the float, the drag, and the buoyancy force on the float.

Ideally, a rotameter is designed and calibrated at the same temperature and pressure, and with the same process fluid, for which it will be used. This ensures that the density of the fluid is the same, although it is often too difficult to replicate the exact conditions of use.

A rotameter is typically designed for one specific gas density and flow range, so without the rotameter being calibrated to those conditions, accuracy will suffer. Calibrating a rotameter will identify the reference conditions in which the rotameter will be used, thus offering the most precise measurements.

Experimental Set Up:

Procedure:

1. Keep the pump bypass valve fully open.
2. Allow the water to pass through the rotameter.
3. Set a specific value of volumetric flow rate on the rotameter.
4. Once the steady state is attained, note down the time taken for the water to collect for a specific height in the collecting tank.
5. Repeat the experiment for different values of rotameter reading.
6. Determine Q_{actual} , $Q_{indicated}$, and plot a graph of Q_{actual} vs $Q_{indicated}$

Calculations:

$$1 \frac{L}{min} = 1.66 \times 10^{-5} \left(\frac{m^3}{s} \right)$$

$$Q_{actual} = (\text{cross sectional area} \times \text{height of water collected}) / \text{time} \quad (m^3/s)$$

$$Q_{indicated} = \text{Rotameter reading} \times 1.66 \times 10^{-5} \quad (m^3/s)$$

Observation & Result Table:

S. No.	Rotameter Reading (LPM)	Height of Water Collected (m)	Time (sec.)	Q_{actual} , m^3/s	$Q_{indicated}$ m^3/s

Plot Graph: Q_{actual} vs $Q_{indicated}$



